PN-ABY-045

Ministry of Water and Irrigation

Water Quality Improvement and Conservation Project

Training Course in Pollution Prevention

Harza Environmental Services, Inc.
Development Associates, Inc.

Development Alternatives, Inc.

The Technical Assistance Team Includes:

Development Alternatives, Inc.
Science Applications International Corp.
Harza Environmental Services, Inc.
Development Associates, Inc.

USAID

United States Agency for International Development
Contract No. 278-0288-00-C-4026-00

May 1995

PN-ABY-045

UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT
Contract No. 278-0288-C-00-4026-00

WATER QUALITY IMPROVEMENT & CONSERVATION PROJECT
Industrial Wastewater Discharge Prevention Program
AMMAN CHAMBER OF INDUSTRY, JORDAN
MINISTRY OF WATER & IRRIGATION, JORDAN

TRAINING COURSE IN POLLUTION PREVENTION

May 1995
Chicago, Illinois U.S.A.

Presented by:

DEVELOPMENT ASSOCIATES, Inc

HARZA Consulting Engineers and Scientists

PREFACE/ACKNOWLEDGMENTS

This training manual was prepared by as a training manual for a short-term US training for pollution prevention and waste minimization (PP/WM) training. The purpose of this training was to provide the participants skills for environmental audit, in order to conduct audits within plant premises to discover the extent of problems, and how to install corrective measures.

This manual was prepared by the Harza Consulting Engineers and Scientists (Harza), Chicago, Illinois, USA with full coordination with the Development Associates, Alexandria, Virginia, USA, under subcontract with the Development Alternatives, Inc., Washington D.C., USA. . This manual was prepared under the direction of Dr. Shawn R. Niaki, P.E., Pollution Prevention Program Director, of Harza, who heads the WQIC component under which the PP/WM training was housed.

Special appreciation is given to Dr. Mohammed Bani Hani, Secretary General of MWI; Eng. Koussai Quteishat, Secretary General of WAJ; Mr. Khaldun Abuhassan, Chairman of the Chamber; Mr. Walid Al-Khathib, Director General of the Chamber; Dr. Muwaffaq Saqqar of MWI, Project Coordinator; and to Development Alternatives, Inc., as represented by Edwin D. Stains, Chief of Party; for their cooperation and confidence.

Schedule for Pollution Prevention Training

Sunday, April 30, 1995

Arrive from Amman, Jordan to O'Hare International Airport, Chicago, Illinois

Meet Harza representative at airport
Check into hotel

Monday, May 1, 1995

Pollution Prevention course at Harza, Chicago, Illinois

Morning Session: Mr. Krishna V. Mayenkar, Vice President

8:30am - 9:30am	Welcome and orientation
9:30am - 10:15am	Introduction to Pollution Prevention
10:15am - 11:00am	Establishing a Pollution Prevention program Video - *Less Is More: Pollution Prevention Is Good Business*
11:00am - 12:00pm	Performing a preliminary waste assessment

Lunch

Afternoon Session: Mr. Robert Nerenberg, Engineer

1:00pm - 2:00pm	Flow diagram case studies
2:00pm - 3:00pm	Performing a detailed waste assessment
3:00pm - 4:00pm	Constructing a material balance

Harza schdall.pp sph
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Tuesday, May 2, 1995

Pollution Prevention course at Harza, Chicago, Illinois

Morning Session: Mr. Robert Nerenberg, Engineer

8:30am - 12:00pm	Material balance exercises Problem - *Ford-Wixom's Phosphate Coating System*

Lunch

Afternoon Session: Mr. Krishna V. Mayenkar, Vice President

1:00pm - 4:00pm	Identifying Pollution Prevention options Video - *Money Down the Drain*

Wednesday, May 3, 1995

Pollution Prevention course at Harza, Chicago, Illinois

Morning Session: Mr. Robert Nerenberg, Engineer

8:30pm - 10:00am	Conducting a feasibility analysis
10:00am - 12:00pm	Implementing, evaluating, and maintaining the Pollution Prevention program

Lunch

Afternoon Session: Guest speakers and discussion

1:00pm - 2:30pm	Presentations by Illinois EPA- Keri Luly, Director of the Office of Pollution Prevention *The role of a state agency in promoting Pollution Prevention & Developing environmental regulatory mandates*
2:30pm - 3:15pm	Presentation by Metropolitan Water Reclamation District of Greater Chicago Jain S. Jain, PhD, P.E., Project Manager *The role of municipal treatment facilities in promoting Pollution Prevention and internal Pollution Prevention practices*
3:30pm - 4:30pm	Conclusions and panel questions

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Thursday, May 4, 1995

Pollution Prevention site visits

Friday, May 5, 1995

Pollution Prevention site visits

Saturday, May 6, 1995

Free day, Chicago, Illinois

Sunday, May 7, 1995

Morning: Free, Chicago, Illinois

Check out of hotel

Afternoon: Travel to West Lafayette, Indiana

Check into hotel

Monday, May 8, 1995

Morning: Site visit to Eli Lilly Company, Lafayette, Indiana

Purdue Industrial Waste Conference, West Lafayette, Indiana

8:00am - 12:00pm	Registration and Sessions
2:00pm - 5:00pm	Sessions

Tuesday, May 9, 1995

Purdue Industrial Waste Conference, West Lafayette, Indiana

9:00am - 12:00pm Sessions
2:00pm - 5:00pm Sessions

Wednesday, May 10, 1995

Morning: **Purdue Industrial Waste Conference, West Lafayette, Indiana**

Check out of hotel
9:00am - 12:00pm Sessions

Afternoon: **Travel to Chicago, Illinois**

Check into hotel

Thursday, May 11, 1995

Morning: **Debriefing at Harza, Chicago, Illinois**

Check out of hotel

Afternoon: **Depart for Amman, Jordan from O'Hare International Airport, Chicago, Illinois**

Site Visit Itinerary
Pollution Prevention Training Course

Thursday, May 4, 1995

All Trainees

8:15 a.m.	Pick up at Hotel
8:15 a.m. - 9:30 a.m.	Travel
9:30 a.m. - 11:30 a.m.	Navistar International - Melrose Park Engine Plant
11:30 a.m. - 12:15 p.m.	Travel
12:15 p.m. - 1:00 p.m.	Lunch
1:00 p.m. - 2:00 p.m.	Corn Products Co. International - Bedford Park Plant
2:00 p.m. - 2:30 p.m.	Travel
2:30 p.m. - 4:30 p.m.	Metropolitan Water Reclamation District of Greater Chicago - Stickney Water Reclamation Plant
4:30 p.m. - 5:30 p.m.	Travel
5:30 p.m.	Drop off at Hotel

Friday, May 5, 1995

Trainee Group 1

6:15 a.m.	Pick up at Hotel
6:15 a.m. - 9:30 a.m.	Travel
9:30 a.m. - 11:30 a.m.	Caterpillar - East Peoria Plant
11:30 a.m. - 2:00 p.m.	Travel
2:00 p.m. - 2:30 p.m.	Lunch
2:30 p.m. - 4:30 p.m.	Commonwealth Edison Will County Power Plant
4:30 p.m. - 5:30 p.m.	Travel
5:30 p.m.	Drop off at Hotel

Trainee Group 2

6:15 a.m.	Pick up at Hotel
6:15 a.m. - 10:30 a.m.	Travel
10:30 a.m. - 12:30 a.m.	Georgia-Pacific - Nekoosa Paper Mill
12:30 a.m. - 1:00 p.m.	Travel
1:00 a.m. - 1:30 p.m.	Lunch
1:30 p.m. - 4:30 p.m.	Stevens Point Brewery
4:30 p.m. - 8:30 p.m.	Travel
8:30 p.m.	Drop off at Hotel

Monday, May 8, 1995

All Trainees

8:15 a.m.	Pick up at Hotel in West Lafayette, Indiana
8:15 a.m. - 9:00 a.m.	Travel
9:00 a.m. - 11:30 a.m.	Eli Lilly and Company - Tippecanoe Laboratories
11:30 a.m. - 12:00 p.m.	Return to Purdue Industrial Waste Conference

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B. Defining Pollution Prevention

C. Pollution Prevention incentives and barriers

2. Establishing a Pollution Prevention Program

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B. Corporate commitment

C. Employee involvement

3. Performing a Pollution Prevention Audit

A. Preliminary waste assessment

1. Conduct initial site survey
2. Define objectives of the waste assessment
3. Develop flow diagrams
4. Develop an audit implementation plan

B. Detailed waste assessment

1. Quantify process inputs
   a. Water inputs
   b. Material inputs
   c. Air inputs
2. Quantify process outputs
   a. Product and by-products
   b. Wastewater
   c. Solid wastes
   d. Air emissions
   e. Reused and recycled wastes
3. Develop a material balance

C. Identifying Pollution Prevention options

1. Process changes
   a. Material substitutions
   b. Technology modifications
   c. Operations and maintenance
2. Product changes

D. Feasibility analysis

1. Environmental evaluation
2. Technical evaluation
3. Economic evaluation

E. The audit report

4. Implementing Pollution Prevention Measures

5. Evaluating the Pollution Prevention Program

A. Quantitative criteria

B. Descriptive criteria

6. Maintaining the Pollution Prevention Program

7. Reference Materials

A. Case studies

B. Articles

C. Audit Forms

1.

INTRODUCTION TO POLLUTION PREVENTION

INTRODUCTION TO POLLUTION PREVENTION

PAST AND PRESENT APPROACHES TO MANAGING INDUSTRIAL WASTES

DEFINING POLLUTION PREVENTION

POLLUTION PREVENTION INCENTIVES AND BARRIERS

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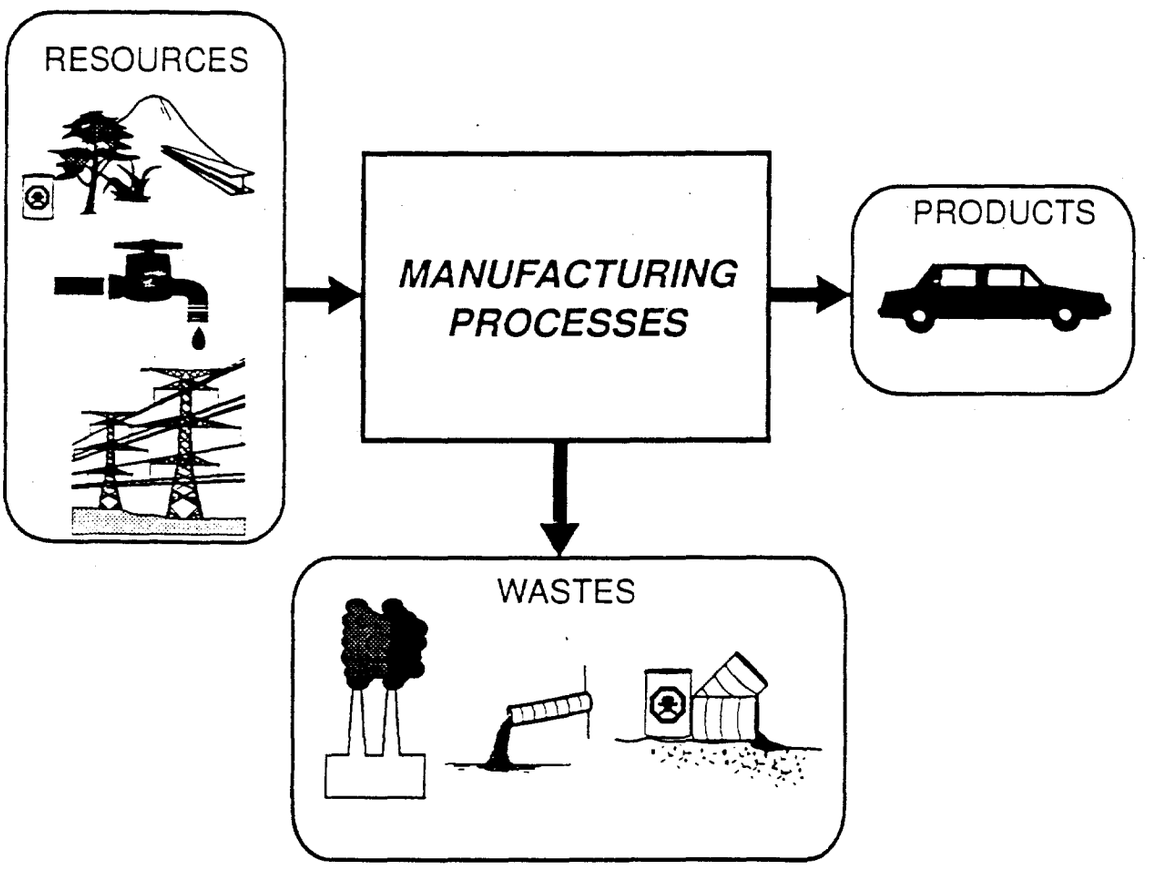
PAST AND PRESENT APPROACHES TO MANAGING INDUSTRIAL WASTES

PAST AND PRESENT APPROACHES TO MANAGING INDUSTRIAL WASTES

UNTREATED DISCHARGE



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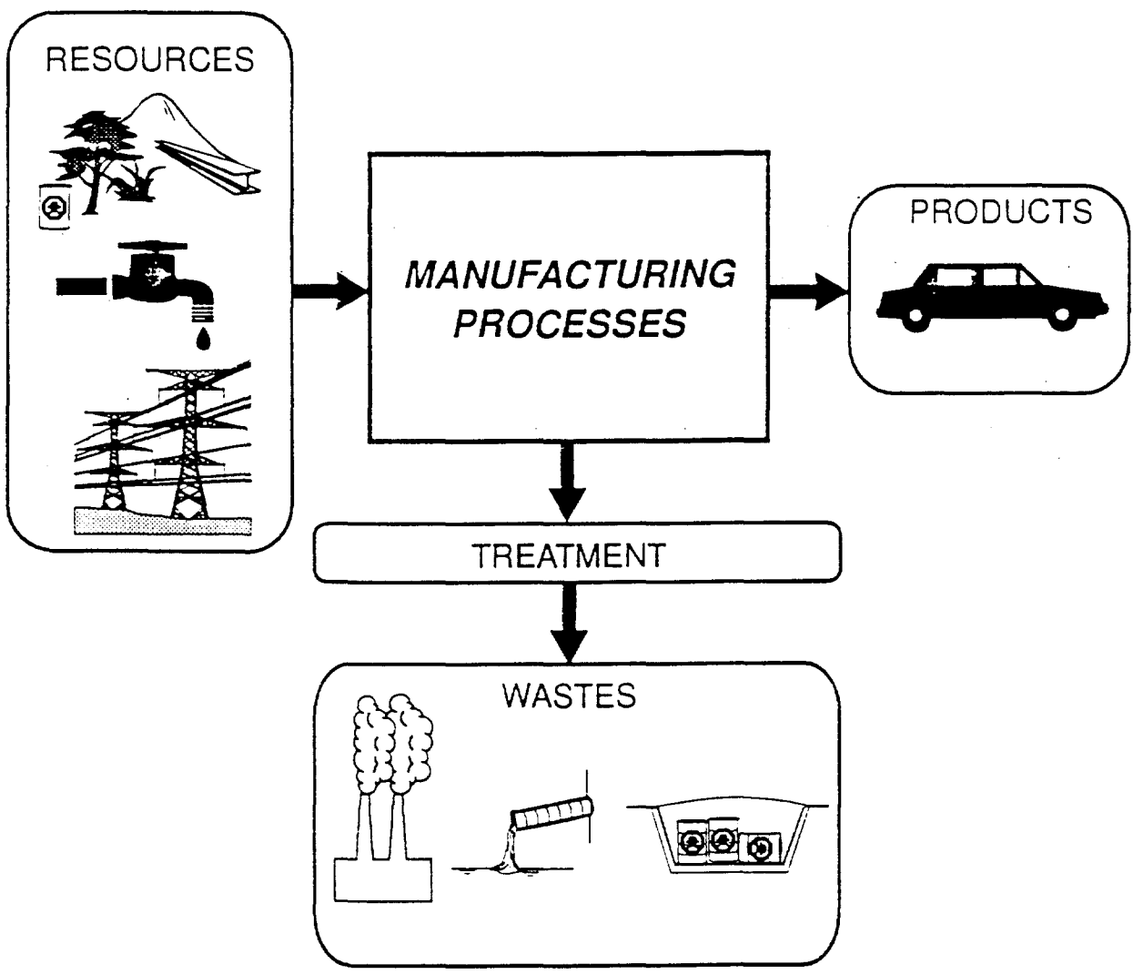
PAST AND PRESENT APPROACHES TO MANAGING INDUSTRIAL WASTES

END-OF-PIPE TREATMENT



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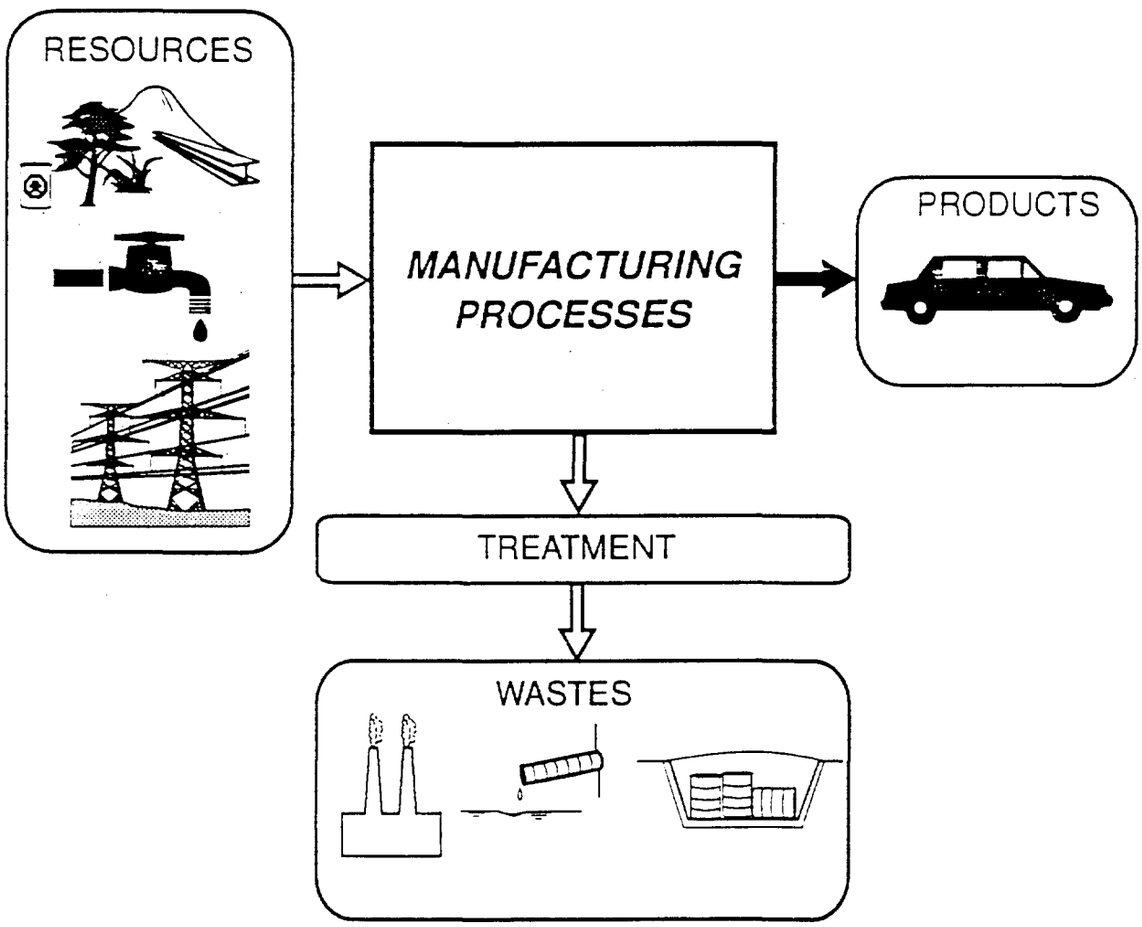
PAST AND PRESENT APPROACHES TO MANAGING INDUSTRIAL WASTES

POLLUTION PREVENTION



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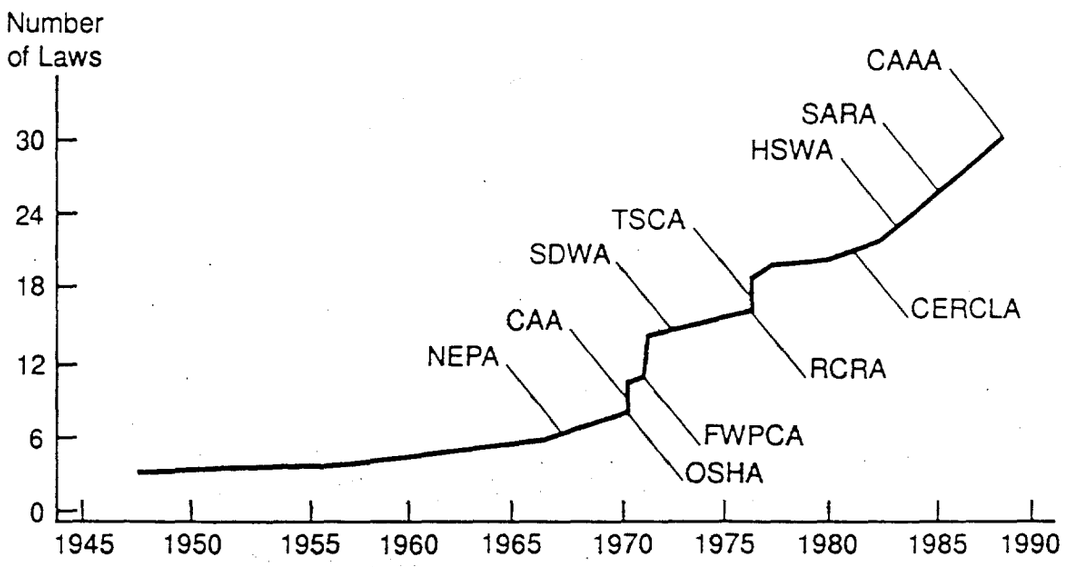
PAST AND PRESENT APPROACHES TO MANAGING INDUSTRIAL WASTES

GROWTH OF U.S. ENVIRONMENTAL LAWS



KEY:

NEPA - National Environmental Protection Act
CAA - Clean Air Act
CAAA - Clean Air Act Amendments (to CAA)
OSHA - Occupational Safety & Health Act
FWPCA - Federal Water Pollution Control Act
SDWA - Safe Drinking Water Act
TSCA - Toxic Substances Control Act
RCRA - Resource Conservation and Recovery Act
HSHA - Hazardous and Solid Waste Amendments (to RCRA)
CERCLA - Comprehensive Environmental Response, Compensation and Liability Act
SARA - Superfund Amendments and Reauthorization Act (to CERCLA)

PAST AND PRESENT APPROACHES TO MANAGING INDUSTRIAL WASTES

SUMMARY OF FEDERAL POLLUTION PREVENTION PROVISIONS

Statutory provision	Pollution prevention authority/ requirement
	Pollution Prevention Act
Findings and policy (42 U.S.C. §13102)	Source reduction is more desirable than waste management and pollution, yet opportunities for source reduction are often not realized.
	Mandates a national policy creating a hierarchy of preferred waste management approaches: source reduction, recycling, treatment, and disposal, all to be conducted in an environmentally safe manner.
EPA activities (42 U.S.C. §13103)	Directs the EPA to create an office (Office of Pollution Prevention at EPA Headquarters, Washington, D.C.) to implement this statute and develop a comprehensive pollution prevention strategy.
State grants for technical assistance programs (42 U.S.C. §13104)	The EPA administrator must make available to states matching grants for programs designed to promote the use of source reduction by businesses. Grants based on: availability of technical assistance to businesses; providing targeted assistance to businesses for whom lack of information is a major impediment to source reduction; and the extent to which training is made available to businesses.
	The administrator must also develop appropriate means by which to measure the effectiveness of these state grant programs.
Source Reduction Clearinghouse (42 U.S.C. §13105)	The EPA must establish the Source Reduction Clearinghouse to compile information on management, technical, and operational approaches to source reduction in a computerized database format.
Source reduction and recycling data collection (42 U.S.C. §13106)	Owners and operators of facilities subject to the annual toxic chemical release form filing requirements of SARA Sec. 313 must include with that filing a toxic chemical source reduction and recycling report for the preceding calendar year. This report must address: the amounts of chemicals released and recycled, source reduction practices aimed at the reported chemicals, methodologies used to identify source reduction opportunities, and future chemical production figures.
EPA Biennial Report (42 U.S.C. §13107)	The EPA must submit a biennial report to Congress that includes an assessment of the effectiveness of the Source Reduction Clearinghouse and the state grant program, analyzes the data generated under Sec. 6607 of the PPA to identify such topics as current trends in source reduction programs in various SIC code industries, regulatory and nonregulatory barriers to source reduction programs, opportunities to use existing federal regulatory programs to overcome existing impediments and promote source reduction in the United States, and identifies and makes recommendations with regard to innovative research and development programs targeting source reduction.

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SOURCE: Freeman, Harry Industrial Pollution Prevention Handbook

PAST AND PRESENT APPROACHES TO MANAGING INDUSTRIAL WASTES

SUMMARY OF FEDERAL POLLUTION PREVENTION PROVISIONS (Continued)

Statutory provision	Pollution prevention authority/ requirement
	Resource Conservation and Recovery Act
Statutory objectives (42 U.S.C. §6902(a)(6))	An express objective of the RCRA is to minimize the generation of hazardous waste and the land disposal of hazardous waste by encouraging process substitution, materials recovery, properly conducted recycling and reuse, and treatment.
National policy (42 U.S.C. §6902(b))	Establishes as national policy that, to the extent feasible, the reduction or elimination of hazardous waste generation should be achieved as expeditiously as possible. Where this cannot be achieved, such wastes should be treated, stored, or disposed so as to minimize the present and future threat to human health and the environment.
Waste minimization requirements for manifests (42 U.S.C. §6922(b))	Hazardous waste generators are required to certify that they have a program in place to reduce the volume or quantity and toxicity of the materials they manage. Such programs must exist to the extent that they are economically practical.
Waste minimization requirements for permits (42 U.S.C. §6925(h))	Hazardous waste treatment, storage, and disposal facilities are required to certify that they have a program in place to reduce the volume or quantity and toxicity of the materials they manage. Such programs must exist to the extent that they are economically practical.
	Clean Air Act
Air toxics (42 U.S.C. §112)	In developing standards to control air toxics, the EPA has authority to require pollution prevention measures, including the installation of control equipment as well as process changes, the substitution of materials, changes to work practices, and operator training and certification.
Mobile source (42 U.S.C. §§241–250, 211)	Requires increasing percentage of fleet vehicles to use alternative fuels and establishes alternatively fueled vehicle pilot program in California.
	Requires the development of reformulated gasoline and oxygenated fuels to reduce air pollutants.
New source review (42 U.S.C. §§170–178)	Requires that new sources located in nonattainment areas use most stringent controls and provide offsets (i.e., emissions reductions from some other source that compensates for residual emissions). Such offsets may be achieved through pollution prevention.
Acid rain (42 U.S.C. §§401–406, 416)	Imposes stringent sulfur dioxide emissions limits and creates system of tradable emissions allowances. Forces power plants to either reduce their emissions to the specified rates or develop or buy emissions allowances, thereby creating market-driven incentives to reduce emissions.
Chlorofluorocarbons (42 U.S.C. §§602–605, 609, 610)	Requires the phaseout of production and sale of CFCs and several other chemicals that have been shown to contribute to the destruction of the stratospheric ozone layer. Also requires the imposition of various controls on CFC-containing products.

SOURCE: Freeman, Harry Industrial Pollution Prevention Handbook

SUMMARY OF FEDERAL POLLUTION PREVENTION PROVISIONS (Continued)

Statutory provision	Pollution prevention authority/ requirement
Clean Water Act	
Effluent limitations (33 U.S.C. §1311)	The EPA has the authority to develop technology-based, industry-specific national limits (implemented through NPDES permits) on the amounts of regulated pollutants a facility is allowed to discharge into the nation's waters. These standards may recommend, and, in some cases, mandate, in-plant controls.
National Pollutant Discharge Elimination System (NPDES) (33 U.S.C. §1342)	Subjects point-source discharges of contaminated stormwater to regulation, including pollution prevention plans.
Toxics Substances Control Act	
Manufacturing and processing notices (15 U.S.C. §2604)	Provides authority for the EPA to issue an order prohibiting or limiting the manufacture, processing, distribution in commerce, use, or disposal, of a chemical substance.
Hazardous chemical substances and mixtures (15 U.S.C. §2605)	Provides the EPA with the authority to promulgate rules to prohibit or limit production or to impose labeling or other requirements (i.e., record keeping, testing requirements, restrictions on the commercial use and disposal, notice of hazards to distributors, users, and the public) when the manufacturing, processing, distribution, use, or disposal of an existing chemical substance or mixture presents an unreasonable risk of injury to health or the environment.
Reporting and record keeping (15 U.S.C. §2607)	Requires the submittal of information about the hazards posed by chemical substances to facilitate regulatory and nonregulatory activity to mitigate known problems. Also supports voluntary submissions of chemical data.
Federal Insecticide, Fungicide, and Rodenticide Act	
Registration of pesticides (7 U.S.C. §136a)	All pesticides that are distributed or sold must be registered with the EPA, unless they are the subject of experimental use permits or an exemption. The administrator has the authority to limit the distribution, sale, or use of any pesticide that is not registered, subject to an experimental use permit, or exempted in order to prevent unreasonable adverse effects on the environment.
Administrative review and suspension (7 U.S.C. §136d)	For pesticides that are not in compliance, or if their use causes unreasonable adverse effects on the environment, the EPA may issue a notice of intent to cancel the pesticide's registration, change its classification, or hold a hearing on these issues. The EPA has authority to supercede the classification process and immediately suspend the registration if necessary to prevent an imminent hazard.
Stop sale, use, removal, and seizure (7 U.S.C. §136k)	Authorizes the EPA to cancel a pesticide if it is causing unreasonable effects on human health and the environment, or suspend its use immediately in order to prevent an imminent hazard. The administrator has the authority to seize pesticides, or to issue "stop sale, use, or removal" orders if the pesticide is in violation of any FIFRA provision, or if the registration has been cancelled.

SOURCE: Freeman, Harry Industrial Pollution Prevention Handbook

DEFINING POLLUTION PREVENTION

DEFINING POLLUTION PREVENTION

POLLUTION PREVENTION IS:

The use of materials, processes, or practices that reduce or eliminate the creation of pollutants or wastes at the source. It includes practices that reduce the use of hazardous and nonhazardous materials, energy, water or other resources as well as those that protect natural resources through efficient use. *(USEPA, 1991)*

DEFINING POLLUTION PREVENTION

POLLUTION PREVENTION

IS :

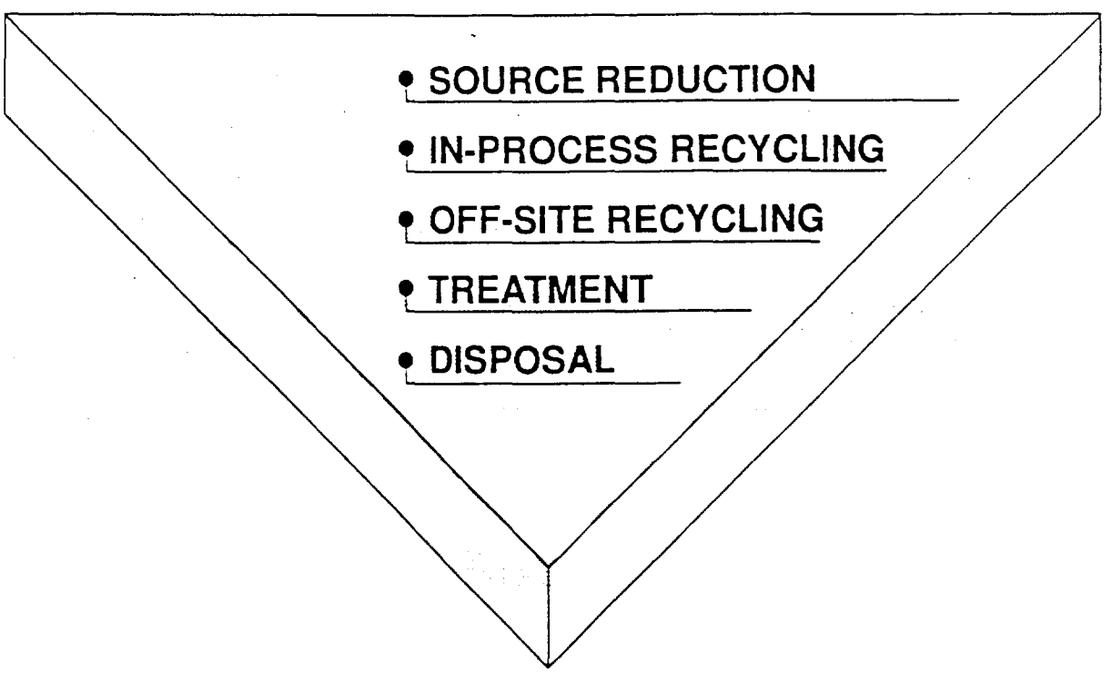
- Source reduction
- Raw material substitution
- Clean technology
- Preventive maintenance
- In-process recycling

IS NOT :

- Off-site waste recycling
- End-of-pipe treatment
- Pollution control
- Disposal

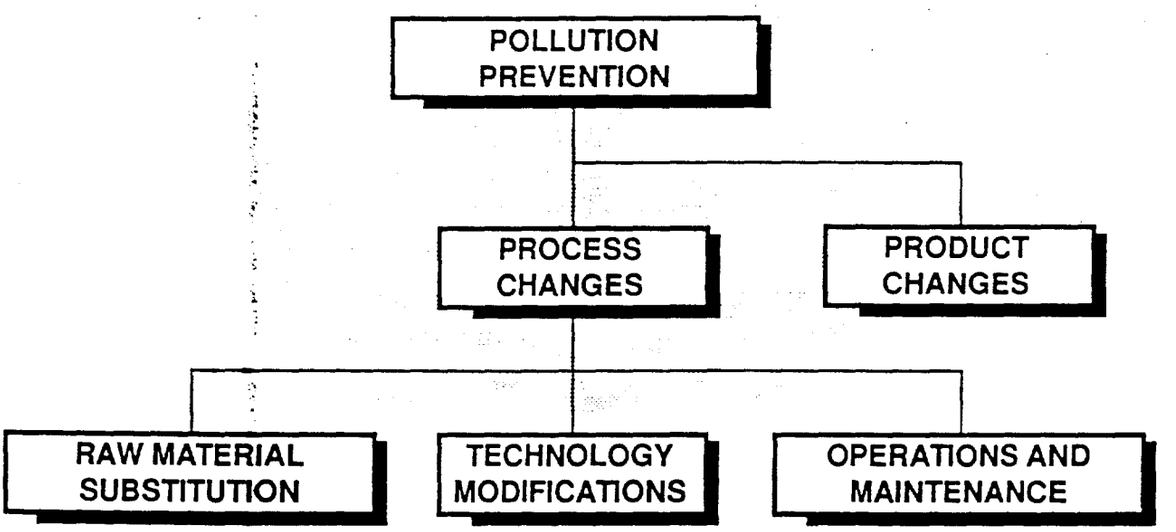
DEFINING POLLUTION PREVENTION

WASTE MANAGEMENT HIERARCHY

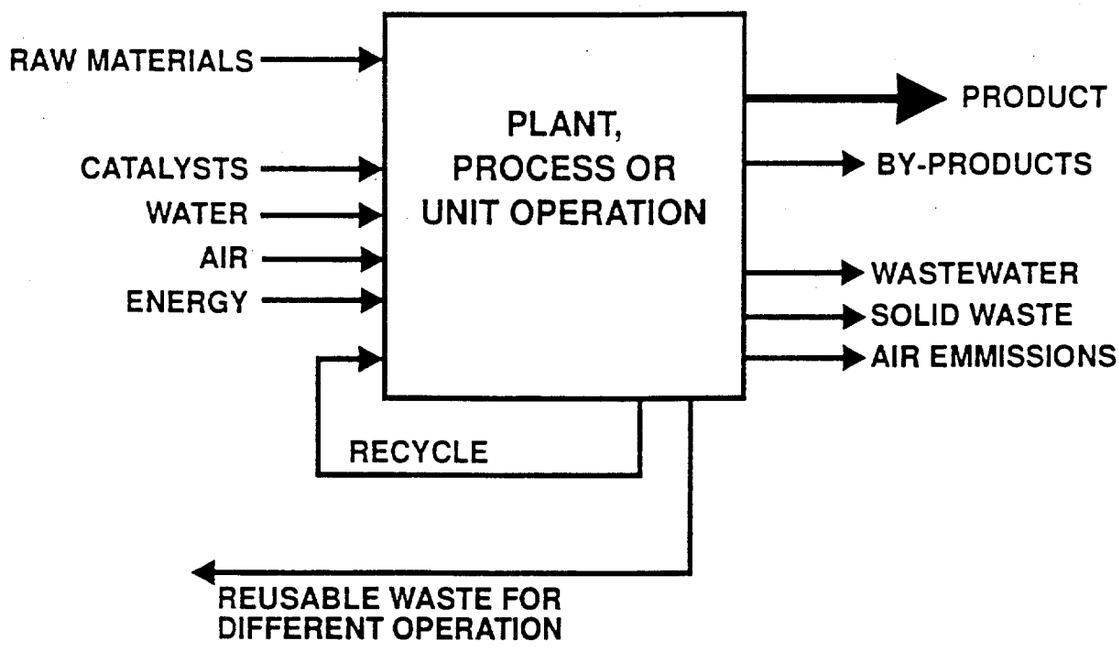


DEFINING POLLUTION PREVENTION

POLLUTION PREVENTION METHODS

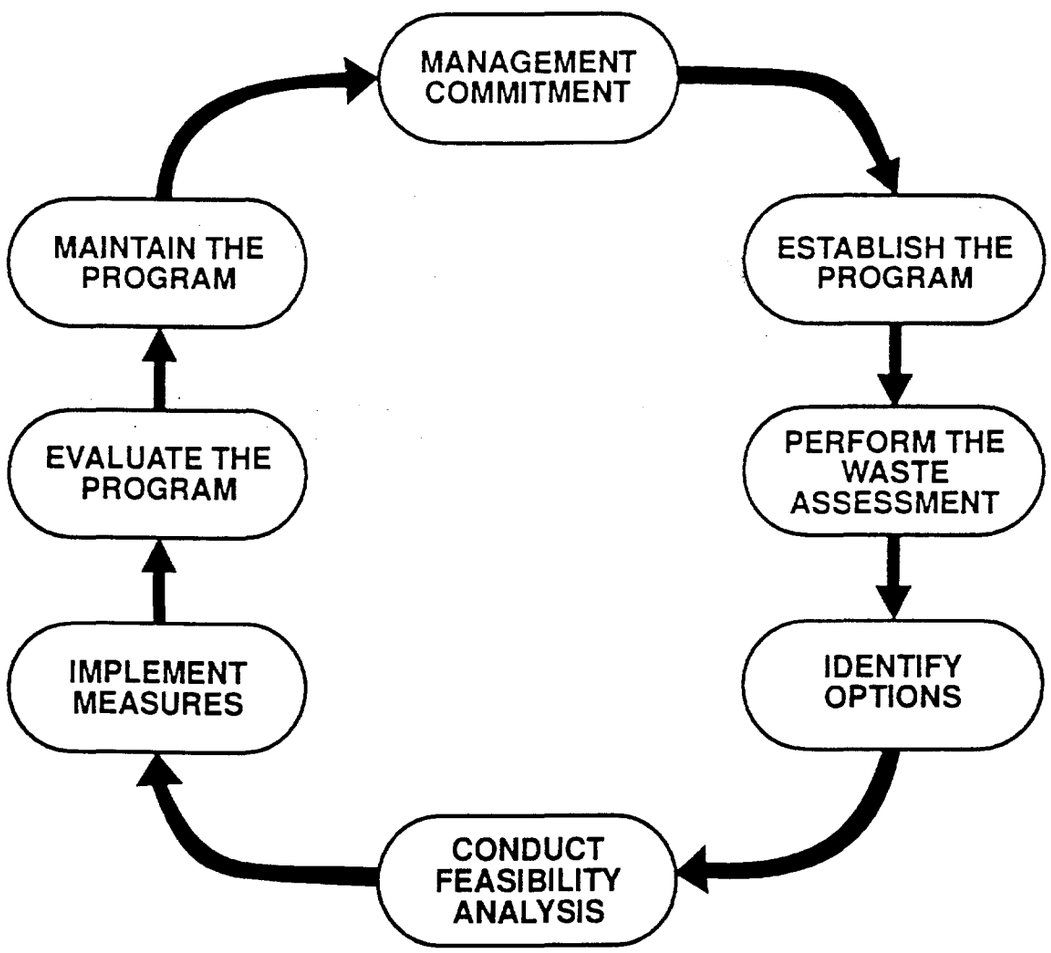


TYPICAL COMPONENTS OF A MATERIAL BALANCE



DEFINING POLLUTION PREVENTION

POLLUTION PREVENTION PROGRAM



POLLUTION PREVENTION INCENTIVES AND BARRIERS

POLLUTION PREVENTION INCENTIVES

- Improved public health and environment
- Reduced risk of liability
- Improved productivity and efficiency
- Reduced operating costs
- Improved company image

POLLUTION PREVENTION INCENTIVES AND BARRIERS

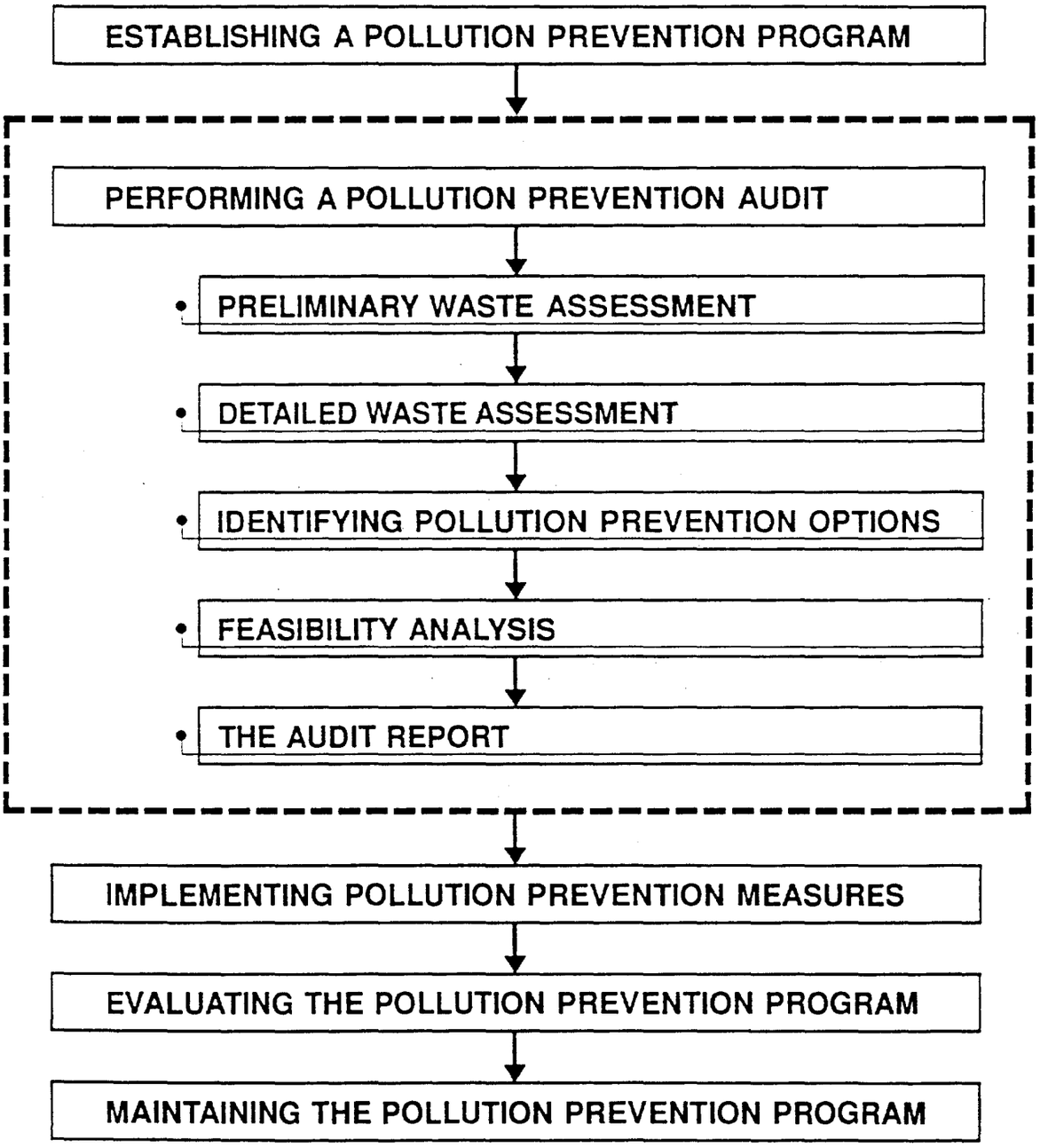
POLLUTION PREVENTION BARRIERS

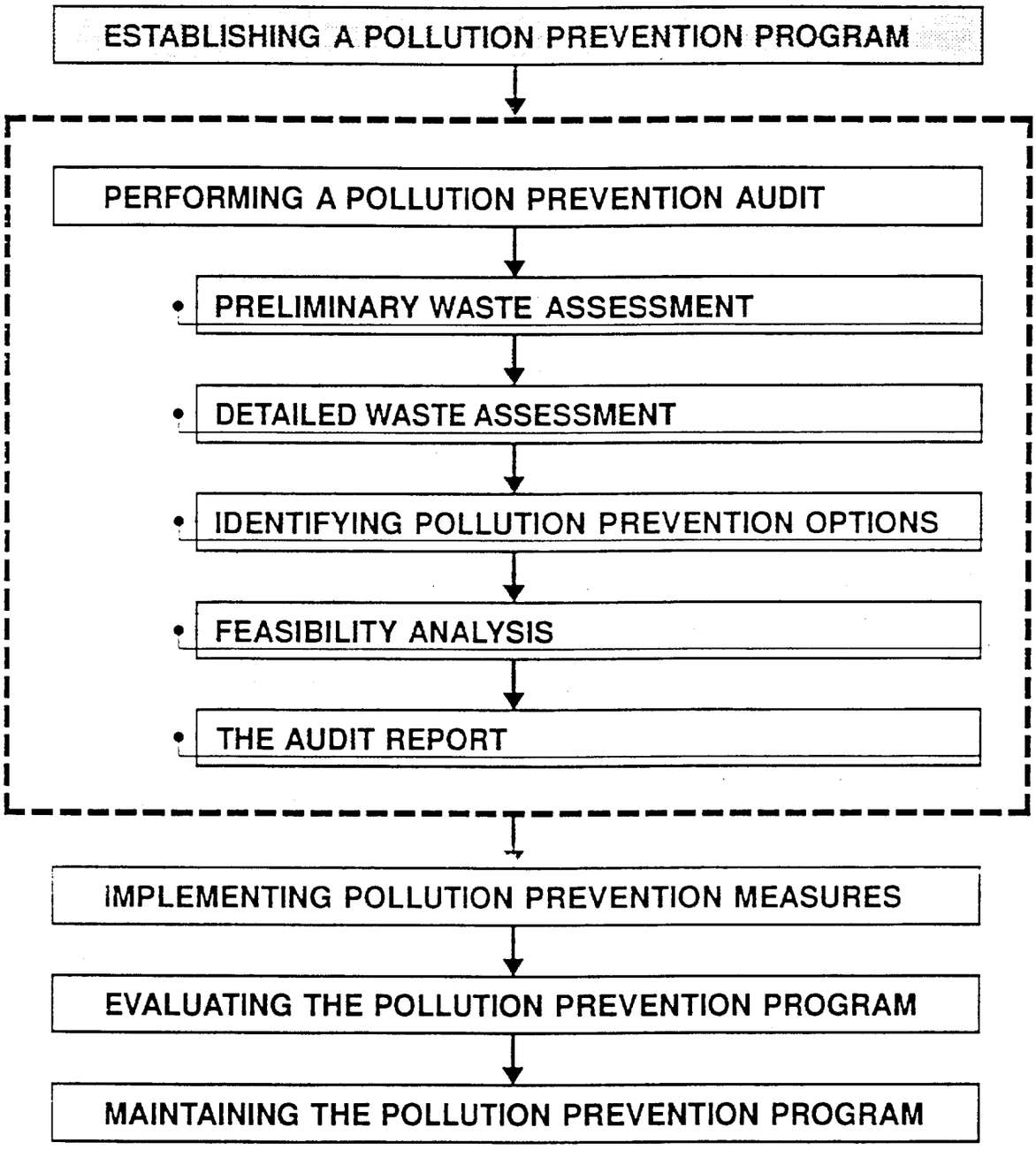
- Lack of governmental mandate
- Lack of management commitment
- Capital requirements
- Lack of information and in-house expertise
- Inertia
- Cost-competitiveness concerns
- Lack of government incentives

2.

ESTABLISHING A POLLUTION PREVENTION PROGRAM

POLLUTION PREVENTION PROGRAM




ESTABLISHING A POLLUTION PREVENTION PROGRAM
PERFORMING A POLLUTION PREVENTION AUDIT
• PRELIMINARY WASTE ASSESSMENT
• DETAILED WASTE ASSESSMENT
• IDENTIFYING POLLUTION PREVENTION OPTIONS
• FEASIBILITY ANALYSIS
• THE AUDIT REPORT
IMPLEMENTING POLLUTION PREVENTION MEASURES
EVALUATING THE POLLUTION PREVENTION PROGRAM
MAINTAINING THE POLLUTION PREVENTION PROGRAM

ESTABLISHING A POLLUTION PREVENTION PROGRAM

PURPOSE : Promote environmental protection with Pollution Prevention by establishing an appropriate regulatory system, securing company management commitment and getting employees involved.

- Government leadership
- Corporate Commitment
- Employee involvement

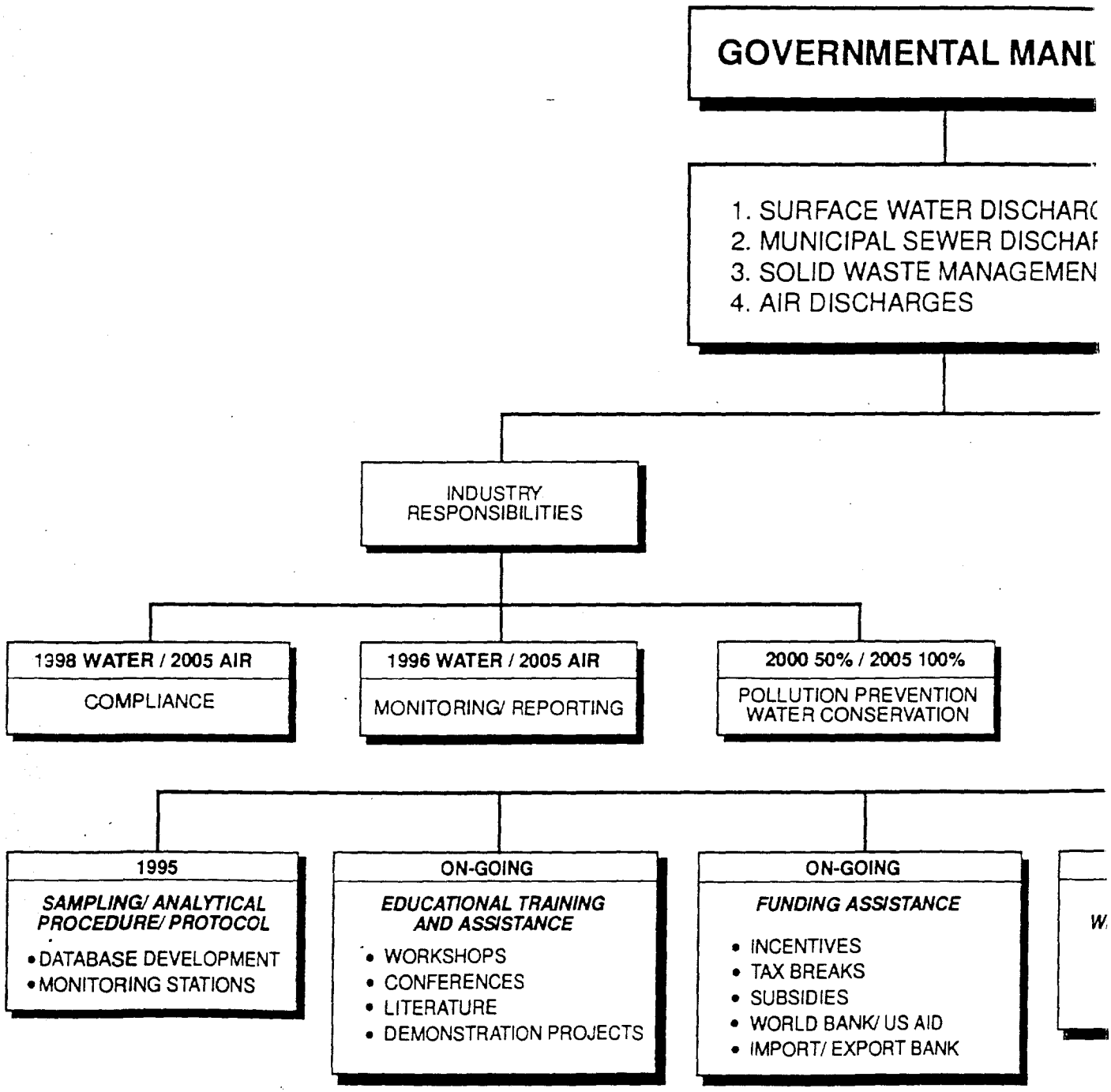
GOVERNMENT LEADERSHIP

GOVERNMENT LEADERSHIP

- Develop an environmental policy mandate
- Enact regulatory statutes to set levels for acceptable discharge
- Provide education and training assistance
- Provide funding assistance (incentives, tax breaks, subsidies, etc.)

GOVERNMENTAL LEADERSHIP

SUGGESTED ENVIRONMENTAL PRC



)TECTION STRATEGY

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RGES
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GOVERNMENT RESPONSIBILITIES

2000

CONSTRUCTION OF ASTE DISPOSAL SITES

- MUNICIPAL
- HAZARDOUS
- MONITORING

1998 WATER / 2005 AIR

COMPLIANCE

- CITY/STATE GOVERNMENT OPERATED FACILITIES

1998 WATER/ 2005 AIR

ENFORCEMENT

- FINES
- PERMIT WITHHOLDING

HARZA

CORPORATE COMMITMENT

CORPORATE COMMITMENT

- Develop waste reduction goals that are challenging yet attainable
- Target specific waste streams and set dates for reductions to be achieved
- Develop a company policy statement that clearly outlines program goals

CORPORATE COMMITMENT

EXAMPLES OF PROGRAM GOALS

- **Provide training to all appropriate staff for Pollution Prevention and environmental awareness by** *(enter date)*
- **Provide facility wide flow and mass balance by** *(enter date)*
- **Characterize all facility waste streams by** *(enter date)*
- **Reduce pollution load by a minimum of** *(enter percentage)* **by** *(enter date)*
- **Reduce production of** *(enter targeted waste)* **in production by a minimum of** *(enter percentage)* **by** *(enter date)*
- **Recycle/reuse a minimum of** *(enter percentage)* **of wastewater by** *(enter date)*
- **Reduce water usage by** *(enter percentage)* **by** *(enter date)*

CORPORATE COMMITMENT

EXAMPLES OF PROGRAM POLICY STATEMENTS

Example policy statement #1

(Company) is committed to excellence and leadership in protecting the environment. In keeping with this policy, our objective is to reduce waste and emissions. We strive to minimize adverse impacts on the air, water, and land through pollution prevention and energy conservation. By successfully preventing pollution at its source, we can achieve cost savings, increase operational efficiencies, improve the quality of our products and services and maintain a safe and healthy workplace for our employees.

(Company)'s environmental guidelines include the following:

- Environmental protection is everyone's responsibility. It is valued and displays commitment to *(Company)*.

- Preventing pollution by reducing and eliminating the generation of waste and emissions at the source is a prime consideration in research, process design, and plant operations. *(Company)* is committed to identifying and implementing pollution prevention opportunities through the encouragement and involvement of all employees.

- Technologies and techniques which substitute non-hazardous materials and utilize other source reduction approaches will be given top priority in addressing all environmental issues.

- *(Company)* seeks to demonstrate its responsible corporate citizenship by adhering to all environmental regulations. We Promote cooperation and coordination between industry, government, and the public toward the shared goal of preventing pollution at its source.

Example policy statement #2

At *(Company)*, protecting the environment is a high priority. We are pledged to eliminate or reduce our use of toxic substances, our release of toxic substances, and our generation of hazardous and other wastes. This approach of preventing pollution at the source is the preferred solution. When the use , release, or generation of hazardous substances cannot be avoided, we are committed to minimizing any undesirable impacts to the air, water, and land.

SOURCE: Illinois Hazardous Waste Reasearch and Information Center, Pollution Prevention, A Guide to Program Implementation

POLLUTION PREVENTION PARTNERSHIP

Wisconsin Rapids Division

Biron Division

Wisconsin River Division

Stevens Point Division

Kraft Division

Water Quality Center

Water Renewal Center

1994 PROGRESS REPORT

Consolidated

CONSOLIDATED PAPERS, INC.

Readers,

Today's business climate demands quality products, demands satisfied customers and demands a reasonable return to our shareholders. Today's business world also demands environmental stewardship.

Consolidated Papers' environmental performance is appropriately measured against high expectations. And while we have spent millions of dollars to meet, as best possible. these expectations, we realize our environmental performance must be based on results — and that's the way it should be.

Our ultimate environmental objective is the prevention of pollution. To that end, Consolidated is an active participant in the Wisconsin Paper Council's Pollution Prevention Partnership with the Wisconsin Department of Natural Resources. Our 1994 Progress Report objectively presents our pollution prevention accomplishments and our plans for the future.

Our commitment to environmental stewardship is genuine. In the future, our business success will be measured not simply by our profitable performance but also on our responsible, cost-effective environmental stewardship — and that, too, is the way it should be.

Patrick F. Brennan

Patrick F. Brennan
President and Chief Executive Officer
Consolidated Papers, Inc.
September 1, 1994

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ENVIRONMENTAL POLICY

As good corporate citizens, we continue to accept our responsibility to preserve and protect natural resources and the environment in the areas in which we operate.

- **Protection of the Environment.** We will employ practical measures to protect the environment. We will conserve and protect the water, air, forest and land resources we use. We will minimize and strive to eliminate any releases to land, air or water that may harm human health or the environment.

- **Conservation of Resources.** We will make sustainable use of renewable resources, such as water, soils and forests. We will conserve nonrenewable resources through efficient use and careful planning.

- **Reduction of Waste.** We will work to prevent waste and pollution at the source whenever possible. New facilities and improvements of existing operations will use manufacturing processes designed to minimize the environmental effects of our operations and will incorporate the best available pollution control equipment.

- **Recycling and Waste Disposal.** We will support recycling programs and will use environmentally safe treatment and disposal practices for waste that is not eliminated at the source or recycled.

- **Compliance.** We will continually monitor and manage all existing facilities to assure that we are meeting or exceeding all legal requirements, and we will implement programs and procedures to ensure compliance. We will conduct comprehensive internal compliance audits to evaluate our progress.

- **Wise Use of Energy.** We will make every effort to use environmentally safe and sustainable energy sources to meet our needs. We will invest in improved energy efficiency and conservation in our operations.

- **Research and Development.** We will support research on improved technologies, safety and pollution control.

- **Leadership.** We will encourage responsible leadership by advising and consulting on legislation and regulation to protect human health and improve the environment.

- **Safe Products.** We are committed to manufacturing safe products that minimize environmental impacts.

- **Risk Reduction.** We will minimize environmental, health and safety risks to our employees and the communities in which we operate by employing safe technologies and operating procedures. We will be constantly prepared for emergencies.

- **Disclosure.** We will continually inform our employees and our publics of our progress in safety and environmental issues. We will cooperate with the media and regulatory agencies in responding to inquiries in a prompt and accurate manner. We encourage employees to report any conditions that could be harmful to the environment or pose health or safety hazards so prompt corrective actions can be taken.

- **Commitment.** The board of directors will be advised of the environmental implications of its decisions. Safety and environmental concerns are a critical responsibility of all employees. All employees and others associated with the company are encouraged to help carry out this policy.

Consolidated Papers, Inc.
Policy Adopted – April 1967
Revised – April 1991

POLLUTION PREVENTION PARTNERSHIP

1994 PROGRESS REPORT

FOR CONSOLIDATED PAPERS, INC.

- ❒ Wisconsin Rapids Division
- ❒ Biron Division
- ❒ Wisconsin River Division
- ❒ Stevens Point Division
- ❒ Kraft Division
- ❒ Water Quality Center
- ❒ Water Renewal Center

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This report has been prepared by Consolidated's environmental staff for the Wisconsin Department of Natural Resources.

Consolidated wishes to thank its many dedicated employees who have helped the company meet and exceed environmental standards that enhance our quality of life as well as our business.

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CORPORATE PROFILE

Consolidated Papers, Inc. (CPI) is a leading producer of enamel papers for the $177 billion printed communications industry, which operates more than 60,000 printing and publishing establishments in the United States and Canada.

Consolidated manufactures and markets a complete line of enamel papers. Commonly referred to as "coated papers," these printing papers are used in many prominent magazines and in an assortment of printed materials, including distinguished books, brochures, advertising communications and corporate annual reports. The company is also the largest manufacturer of lightweight coated specialty papers, which are used in food and consumer product packaging and labeling. Other products manufactured by Consolidated include paperboard products and custom-designed corrugated displays and containers.

In 1993, Consolidated ranked 372nd among the Fortune 500 Largest U.S. Industrial Corporations. The company's manufacturing operations and executive offices are concentrated in central Wisconsin.

Consolidated owns and manages 671,642 acres of forests in Wisconsin, Michigan and Ontario, Canada. Our paper mills are near sizable forests that belong to tree farmers and national, state and county governments. From these lands, from our own renewable forests and from sources of recycled fiber, wood and wood fiber are transported to Consolidated's mills for conversion to pulp and paper. The finished products then travel onward to our customers throughout the United States and abroad.

Consolidated's manufacturing and wastewater treatment operations included in this report are:

- **Wisconsin Rapids Division**
  Manufactures enamel (coated) printing papers, heavier-weight free-sheet grades and paperboard.

- **Biron Division**
  Manufactures coated printing papers, lightweight groundwood grades. Produces groundwood pulp and thermomechanical pulp at its on-site mechanical pulp mill.

- **Wisconsin River Division**
  Manufactures coated printing papers, lightweight groundwood grades. Produces groundwood pulp and thermomechanical pulp at its on-site mechanical pulp mill.

- **Stevens Point Division**
  Manufactures lightweight coated specialty papers.

- **Kraft Division**
  Manufactures kraft (chemical) pulp and produces power.

- **Water Quality Center**
  Wastewater treatment plant that treats process wastewater from Wisconsin Rapids, Biron and Kraft divisions.

- **Water Renewal Center**
  Wastewater treatment plant that treats process wastewater from Wisconsin River and Stevens Point divisions.

MANAGEMENT COMMITMENT

Consolidated Papers' Management Commitment to Environmental Stewardship and Pollution Prevention

At Consolidated, we acknowledge our responsibility to protect the environment in which we live. We understand that environmental protection is necessary for the production of high-quality paper products and to protect the environment we value: clean air and water, abundant forests, and the land and wildlife around us.

In 1967, we adopted our first environmental policy statement and updated it in 1991. It displays our commitment to conserve and protect our water, air and land resources. Our dedication to complying with environmental laws and regulations is reinforced by the company's organizational structure. Our environmental affairs staff maintains direct access to top management, ensuring that the necessary resources are provided to maintain the company's good environmental performance.

... pollution prevention is not a new concept at Consolidated Papers.

Pollution prevention is a major environmental concern in the 1990s. However, pollution prevention is not a new concept at Consolidated Papers. We have always preferred to eliminate pollution at the source rather than treat it after it has been generated. Our recognition of the importance of pollution prevention is documented in our corporate environmental policy that states:

> "We will work to prevent waste and pollution at the source whenever possible. New facilities and improvements of existing operations will use manufacturing processes designed to minimize the environmental effects of our operations and will incorporate the best available pollution control equipment."

Consolidated remains committed to addressing environmental improvements by taking an aggressive approach, while maintaining cost-effective compliance with all regulations.

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ACCOMPLISHMENTS

Consolidated Papers' Pollution Prevention Accomplishments

A discussion of Consolidated Papers' pollution prevention activities and accomplishments follows. This discussion addresses the following five areas:

- **Air Pollution Control**
- **Wastewater Discharges**
- **Solid Waste**
- **Hazardous Materials/Hazardous Waste**
- **Other Pollution Prevention Achievements**

AIR POLLUTION CONTROL

Whenever possible, CPI uses "clean" fuels.

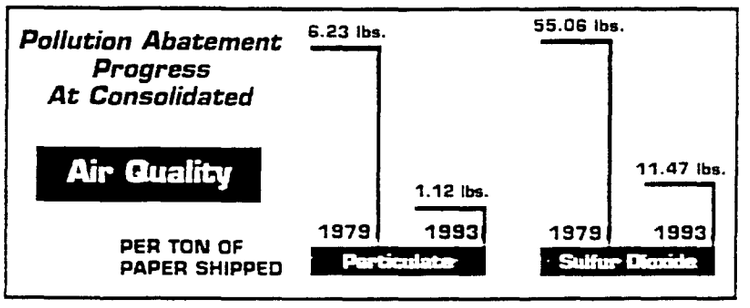
Most of the air pollutants generated by CPI are the result of fuel combustion to power our pulp and papermaking operations. Two of the most significant pollutants from fuel combustion are particulate matter (dust) and sulfur dioxide (SO_2).

Particulate matter is controlled by using pollution control equipment such as electrostatic precipitators, multiclones and scrubbers. The removal efficiencies for this equipment range from approximately 92% to 99.8%.

Whenever possible, CPI uses "clean" fuels. Low-sulfur coal is burned in four of our five coal-fired boilers. This results in very low sulfur dioxide emissions. Coal with a higher sulfur content is required for proper operation of our coal-fired cyclone boiler. Since 1986, all of CPI's production expansions have resulted in the installation of natural-gas-fired boilers instead of coal-fired boilers. Natural gas is a "clean" fuel and natural-gas boilers emit relatively few pollutants. We have also converted three older coal-fired boilers to natural-gas-fired boilers to reduce emissions.

(Continued)

We also burn bark generated from our pulping operations in some of our boilers. Bark is a low-sulfur energy source and produces very low sulfur dioxide emissions. Rather than dispose of the bark in a landfill, we burn it to recover the energy, thus making beneficial use of a waste byproduct. We also combust recycled pulping liquors for energy recovery. In 1993, 45% of the energy we used was internally generated from recycled pulping liquors and wood and bark residues.



Our particulate matter and SO_2 pollution reduction progress is presented in the graphs shown here.

Besides emissions from fuel combustion, there are also emissions from the pulp and papermaking processes. A summary of other air-related pollution prevention accomplishments follows:

- The use of a heavy black-liquor oxidation system to reduce sulfur emissions from the recovery boilers.
- The use of high-efficiency wet scrubbing systems to remove chlorine and chlorine dioxide emissions from the bleach plant.
- The installation of brownstock gas and noncondensible gas collection systems to collect gases generated during the kraft pulping process. The gases are then incinerated in the power boilers to destroy the total reduced sulfur and organic compounds and to recover their energy value. In 1993, over 3 million pounds of methanol, acetone, methyl ethyl ketone and hydrogen sulfide were collected and incinerated.
- Our mechanical pulps are already bleached using a totally chlorine-free process.
- Product substitution to a lower free-formaldehyde product results in reduced formaldehyde emissions at our Stevens Point Division. At our other manufacturing facilities, product substitution has eliminated the use of formaldehyde-containing products resulting in the elimination of formaldehyde emissions from these papermaking processes.

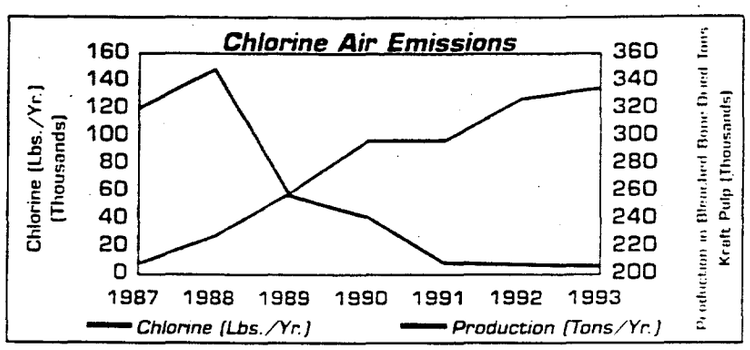
(Continued)

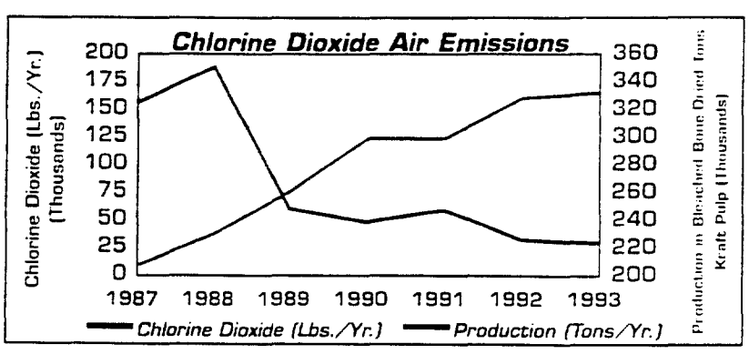
Our mechanical pulps are already bleached using a totally chlorine-free process.

- The elimination of the ammonia stearate cooking process, thus eliminating ammonia emissions of approximately 4,700 pounds per year from our Wisconsin Rapids Division.

- CPI is in the process of eliminating the use of chlorinated solvents in spray cans.

- The use of less elemental chlorine and more chlorine dioxide, hydrogen peroxide and oxygen for kraft pulp bleaching, resulting in reduced air emissions of chlorine and other chlorinated organics such as chloroform. Reductions in the air emissions of these substances have been achieved even with increasing production. The following graphs present the declining air emissions of chlorine, chlorine dioxide, chloroform and the increasing pulp production at our Kraft Division from 1987 to 1993.





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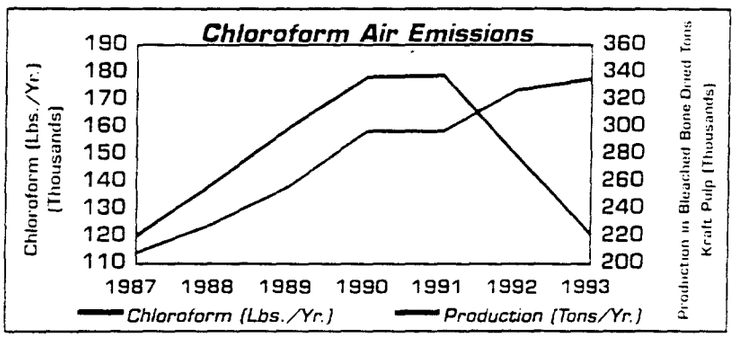
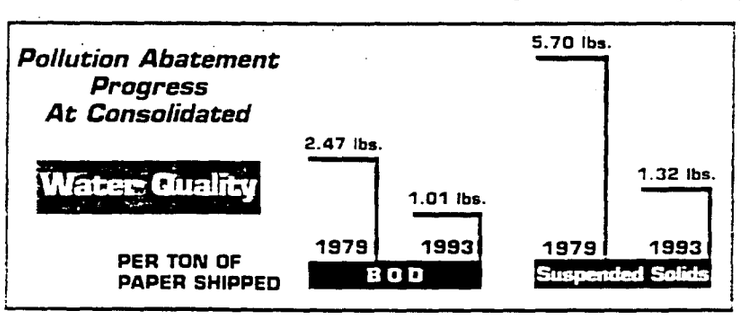


WASTEWATER DISCHARGES

CPI owns and operates two wastewater treatment plants that treat about 33 million gallons of process wastewater daily. The plants remove about 98% of biological oxygen demand (BOD) and suspended solids material. The plants currently operate at about 14% of their allowable discharge limits making them among the most efficient wastewater treatment plants in North America.



Consolidated's pollution prevention work has been directed at reducing our wastewater discharges to the Wisconsin River. The adjacent graphs present the favorable progress we have made from 1979 to 1993.

Examples of the projects completed that produced these reductions are:

- Installation of oxygen delignification on the kraft hardwood and softwood lines. This has allowed us to take material that was being discharged for treatment and use it as a fuel. Oxygen delignification has been used on the hardwood line since 1986. Softwood oxygen delignification was installed in 1993.

(Continued)

- The conversion of the kraft softwood digester to modified continuous cooking. This improves pulp delignification in the digester and reduces the amount of lignin that must be removed in the bleach plant. This reduces the amount of material discharged for treatment.

- The expansion of our Water Quality Center wastewater treatment plant as a result of production increases at our Wisconsin Rapids and Kraft divisions.

- The expansion of our Water Renewal Center wastewater treatment plant. After the expansion, this plant was able to treat process wastewater from our Stevens Point Division. This substantially improved the degree of treatment of Stevens Point's wastewater.

The company is reusing as much process water as possible before it is treated.

We are continually trying to reduce the volume and quantity of wastewater requiring treatment. Some examples of how this is accomplished include:

- Consolidated features coating blend-back systems that are being implemented to recycle coating after a grade change rather than disposing of the coating.

- The company is reusing as much process water as possible before it is treated.

- CPI has an internal program to track flow, suspended solids and BOD discharge losses on a monthly basis.

- Consolidated uses a progressive program to assess significant self-imposed financial penalties if process water discharge targets are not met.

In addition, we are reducing the quantities of toxic substances that are used or inadvertently generated during our processes and become part of our wastewater. The concentration of these toxic substances in the wastewater is usually small. Programs currently in place to address these substances are:

- Evaporator condensates from kraft pulping are steam stripped to remove volatile organic compounds from the wastewater. The substances are burned for energy recovery.

- Our chlorine-reduction program reduces the amount of elemental chlorine used to bleach kraft pulp. This results in reduced amounts of dioxin (2,3,7,8-TCDD), furan (2,3,7,8-TCDF) and other chlorinated organics such as chloroform from being generated and placed into the wastewater for treatment. Our treated effluents have non-detectable dioxin levels.

(Continued)

- ❒ Spill-prevention plans have been developed for each facility. These plans identify potential spill situations and require preventive measures to eliminate, to the extent possible, any accidental nonpermitted discharges.
- ❒ Stormwater runoff from most chemical unloading areas has been diverted to process sewers. The runoff from these areas is then collected and is treated at a wastewater treatment plant.

SOLID WASTE

As a result of the chlorine-reduction program and other process changes, the dioxin levels in our sludge, to date, have been reduced approximately 99.6% to about one part per trillion.

Consolidated is an industry leader in finding alternatives to landfill disposal. In 1983, we became the first paper company in Wisconsin to receive approval to landspread our wastewater treatment plant sludge rather than place it in a landfill. This practice took a large part of our solid waste and turned it into a valuable soil enhancer and fertilizer for farmers in the central Wisconsin area. We also developed a sludge composting operation that successfully operated for years. Both programs were voluntarily suspended because of concerns over dioxin. As a result of the chlorine-reduction program and other process changes, the dioxin levels in our sludge, to date, have been reduced approximately 99.6% to about one part per trillion. We recently received DNR approval and have resumed our landspreading program.

We also continue to investigate additional alternatives to landfilling. Some of the alternatives we are exploring include:

- ❒ Fiber recovery from sludge
- ❒ Landspreading boiler ash as a liming agent
- ❒ Landspreading lime sludge as a liming agent
- ❒ Use of boiler ash as an aggregate in cement
- ❒ Incineration of our sludge for energy recovery

(Continued)

CPI is reducing the amount of trash landfilled. A recycling program has been instituted at all of CPI's facilities. Employees recycle office paper, aluminum cans, glass, etc. Separate disposal bins are available to collect these recyclables. As a result of this and other trash-reduction programs, CPI was able to reduce the amount of trash sent to landfills by 19% during 1993.

Consolidated also is participating in the National Office Paper Recycling Challenge. This involves collecting office paper for recycling, buying products containing wastepaper and creating a paper recycling initiative. Progress to date includes meeting our goal of collecting 100% of our office paper for recycling. Progress toward our goal of buying products containing wastepaper is ongoing. We continue to investigate the purchase of products that contain recycled wastepaper.

As a result of this and other trash-reduction programs, CPI was able to reduce the amount of trash sent to landfills by 19% during 1993.

Whenever possible, barrels are being replaced with returnable tote bin systems. This greatly reduces the number of barrels that are landfilled for disposal. Where barrels continue to be used, we have initiated a container management policy so chemical losses are minimized and barrels are properly cleaned and reconditioned for reuse.

For nearly two decades, CPI has provided a wastepaper collection site that serves as a deposit point for the public's wastepaper. We have been using post-consumer recycled wastepaper to make paperboard since 1917. Annually, we recycle about 40,000 tons of post-consumer unprocessed wastepaper and transform it into paperboard. Some of the coated paper we produce also contains recycled fiber. Deinked post-consumer fiber is used to make our coated recycled printing paper grades. We purchase hundreds of tons of recycled fiber each month. Our recycling efforts will continue to increase. Consolidated will pursue every opportunity to expand our use of recycled fiber, while continuing to meet our customers' demands for high-quality papers.

All of the activities mentioned above are making beneficial use of waste products. This results in less material being placed in both company-owned and municipal landfills.

HAZARDOUS MATERIALS/WASTE

We are reducing or eliminating the generation of hazardous waste. This is accomplished by screening all hazardous-material purchases to ensure that all products are environmentally acceptable. Corporate policy prohibits the purchase of anything that contains asbestos, mercury, zinc, arsenic, lead, formaldehyde, PCB, pentachlorophenols

and trichlorophenols. Whenever possible, we substitute hazardous products with nonhazardous ones. We are constantly working with suppliers to reformulate products to remove hazardous ingredients. If possible, we substitute raw materials in order to reduce or eliminate the generation of hazardous substances or hazardous waste.

As a result of these screening programs, only a small amount of hazardous waste is generated and disposed of by Consolidated. Parts-washer solvent and waste xylene from painting operations account for the majority of the hazardous waste. The parts-washer solvent currently accounts for about 70% of the hazardous waste generated. CPI's facilities have optimized the use of these parts-washer systems. This has reduced the amount of parts-washer solvent used and the amount of hazardous waste generated. We are currently working with manufacturers to determine if a reformulated parts-washer solvent will remain nonhazardous after use, thereby eliminating the generation of hazardous waste. The small amount of hazardous waste generated is disposed of in strict accordance with all state and federal environmental regulations.

The small amount of hazardous waste generated is disposed of in strict accordance with all state and federal environmental regulations.

CPI has a recycling program to collect all used mercury vapor, fluorescent and incandescent light bulbs. These bulbs are being disposed of in strict accordance with all state and federal environmental regulations to prevent mercury and lead contamination to the environment.

We are working on eliminating the use of chemical products that contain nonylphenol ethoxylates. Products used at CPI containing nonylphenol ethoxylates have been identified. The suppliers have been contacted and directed to reformulate these products or find replacement products. To date, approximately two-thirds of these products have been replaced.

OTHER ACHIEVEMENTS

- CPI's softwood kraft pulp is elemental chlorine-free (ECF) and the softwood kraft pulp we purchase for use in our publication grades is ECF. Our hardwood pulp will be ECF by the end of 1996. In the meantime, we are committed to purchasing ECF hardwood pulp for use in our publication grades as soon as it becomes available.

(Continued)

The environmental impact of all company projects is assessed prior to approval, with an emphasis on pollution prevention.

- ❑ We have properly removed from service all of our known underground storage tanks resulting in less risk of groundwater contamination. These removals have been done in accordance with DNR guidelines.

- ❑ All transformers that contained PCBs have either been removed or refilled with non-PCB cooling oil.

- ❑ Wherever possible, CPI has replaced instruments containing mercury with nonhazardous substitutes. This greatly reduces the chance of environmental contamination from accidental releases.

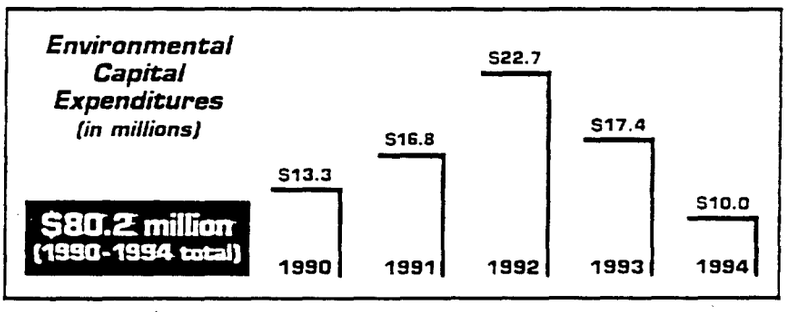
- ❑ Asbestos insulation is present in many older parts of our manufacturing facilities. CPI has implemented asbestos removal programs. These ongoing removal programs not only "clean up" the workplace, but they also reduce the chance of any environmental exposure from accidental releases.

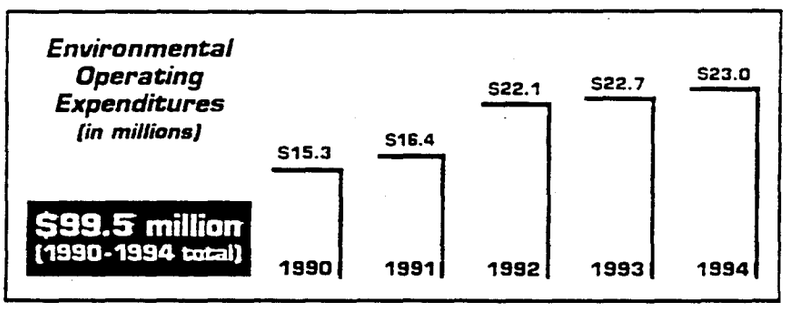
- ❑ The environmental impact of all company projects is assessed prior to approval, with an emphasis on pollution prevention. An environmental impact review must be completed for all proposed projects addressing their effects on air, water and land (including noise). Documentation is also required explaining how compliance with all environmental regulations will be maintained.

- ❑ All of our operating facilities have active pollution prevention teams to define pollution prevention/reduction objectives. Any pollution reduction project must not have an adverse effect on quality or productivity. These teams are able to target products for substitution, modify process operations and install state-of-the-art control technology.

ENVIRONMENTAL EXPENDITURES

Consolidated remains dedicated to cost-effective compliance with all federal and state environmental monitoring conditions and permit limitations in place to protect public health and welfare. To ensure our compliance, we place emphasis on capital and operating expenditures for environmental equipment.





FUTURE GOALS

By the end of 1996, we will eliminate the use of elemental chlorine in the kraft pulp bleaching process.

- CPI is participating in the EPA's 33/50 voluntary reduction program. Chloroform is CPI's target chemical for the 33/50 program. Our goal is to achieve a 50% reduction, from the 1988 levels, for environmental releases and transfers of chloroform by 1995. Preliminary data indicate that we have already achieved a greater than 50% reduction in chloroform emissions. Consolidated will continue to investigate process modifications and control technologies to achieve further reductions. At this time, we are planning to achieve these further reductions in chloroform emissions by the late 1990s.

- CPI has a chlorine-reduction program to reduce the amount of elemental chlorine used to bleach kraft pulp. By the end of 1996, we will eliminate the use of elemental chlorine in the kraft pulp bleaching process. Our kraft pulp will then achieve a position commonly referred to as elemental chlorine-free, or ECF. Our mechanical pulps are already bleached using a totally chlorine-free process.

- In 1994, our Water Quality Center will reduce its wastewater discharges of ammonia by 15% from its 1993 levels.

- In 1995, our Biron Division will install equipment to collect, dewater and burn mechanical pulp mill fiber losses. This project is estimated to reduce suspended solids losses to the wastewater treatment plant by about 18,000 pounds per day.

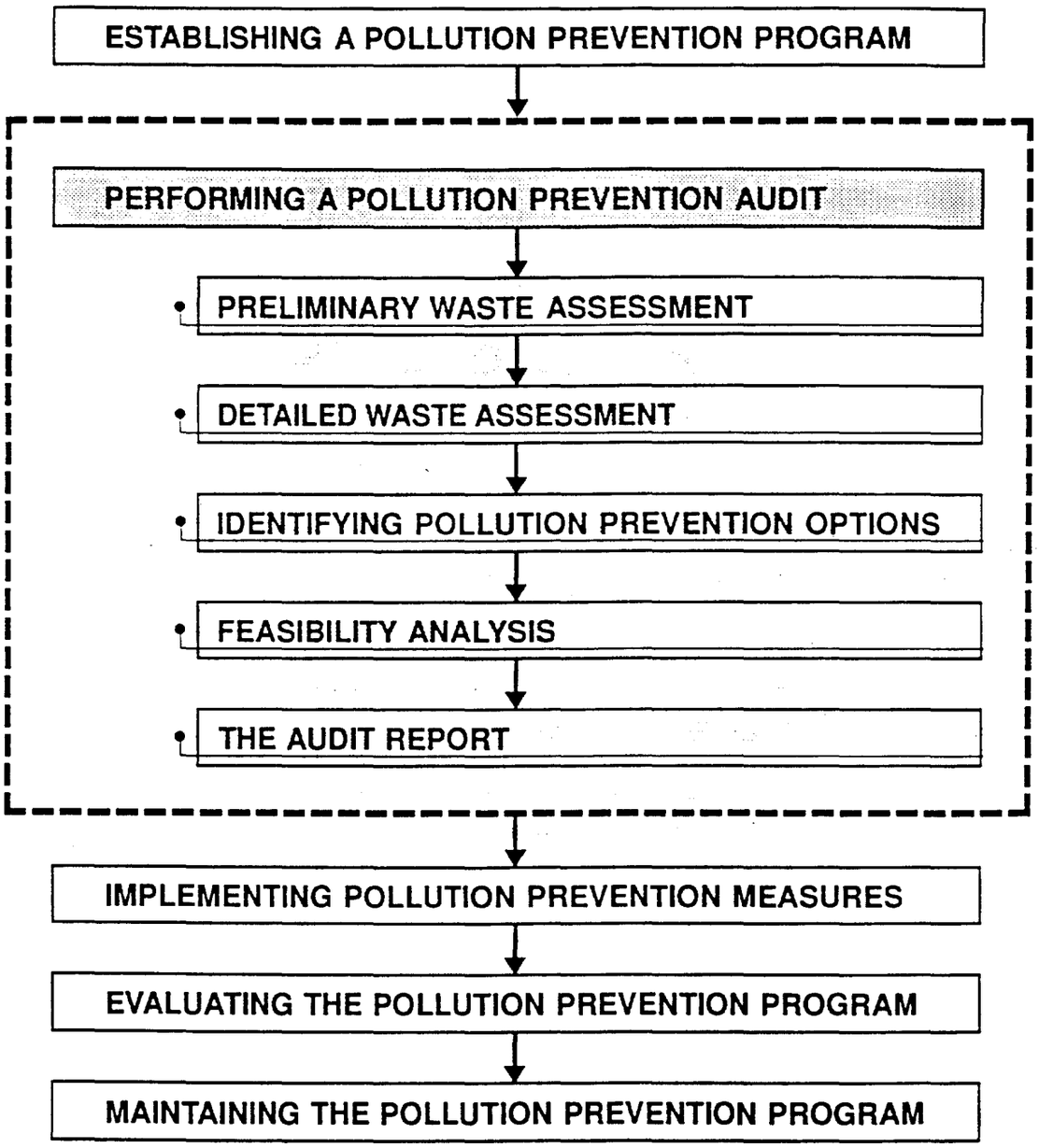
- CPI's manufacturing facilities will continue to minimize the amount of chlorine used to disinfect river water and other fresh water prior to use in their processes. In recent years, many of CPI's facilities have reduced the amount of chlorine used as a biocide. A biocide replacement for chlorine continues to be investigated.

- Consolidated continues to investigate process modifications and control technologies to reduce methanol, acetone and methyl ethyl ketone air emissions from our kraft pulping process. We are planning to achieve significant reductions in methanol, acetone and methyl ethyl ketone air emissions by the late 1990s. Our Water Quality Center is currently removing greater than 99% of the methanol in our wastewater.

EMPLOYEE INVOLVEMENT

EMPLOYEE INVOLVEMENT

- Help define company goals and policy
- Review processes and operations to determine where and how materials are used and hazardous wastes are generated
- Recommend ways to eliminate or reduce waste production at the source
- Find ways to involve suppliers and customers


ESTABLISHING A POLLUTION PREVENTION PROGRAM
PERFORMING A POLLUTION PREVENTION AUDIT
PRELIMINARY WASTE ASSESSMENT
DETAILED WASTE ASSESSMENT
IDENTIFYING POLLUTION PREVENTION OPTIONS
FEASIBILITY ANALYSIS
THE AUDIT REPORT
IMPLEMENTING POLLUTION PREVENTION MEASURES
EVALUATING THE POLLUTION PREVENTION PROGRAM
MAINTAINING THE POLLUTION PREVENTION PROGRAM

PERFORMING A POLLUTION PREVENTION AUDIT

PURPOSE : Systematically define sources, quantities and types of waste being generated in order to highlight process inefficiencies and generate pollution preventing options.

- Preliminary waste assessment
- Detailed waste assessment
- Identifying Pollution Prevention options
- Feasibility analysis
- The audit report

PRELIMINARY WASTE ASSESSMENT

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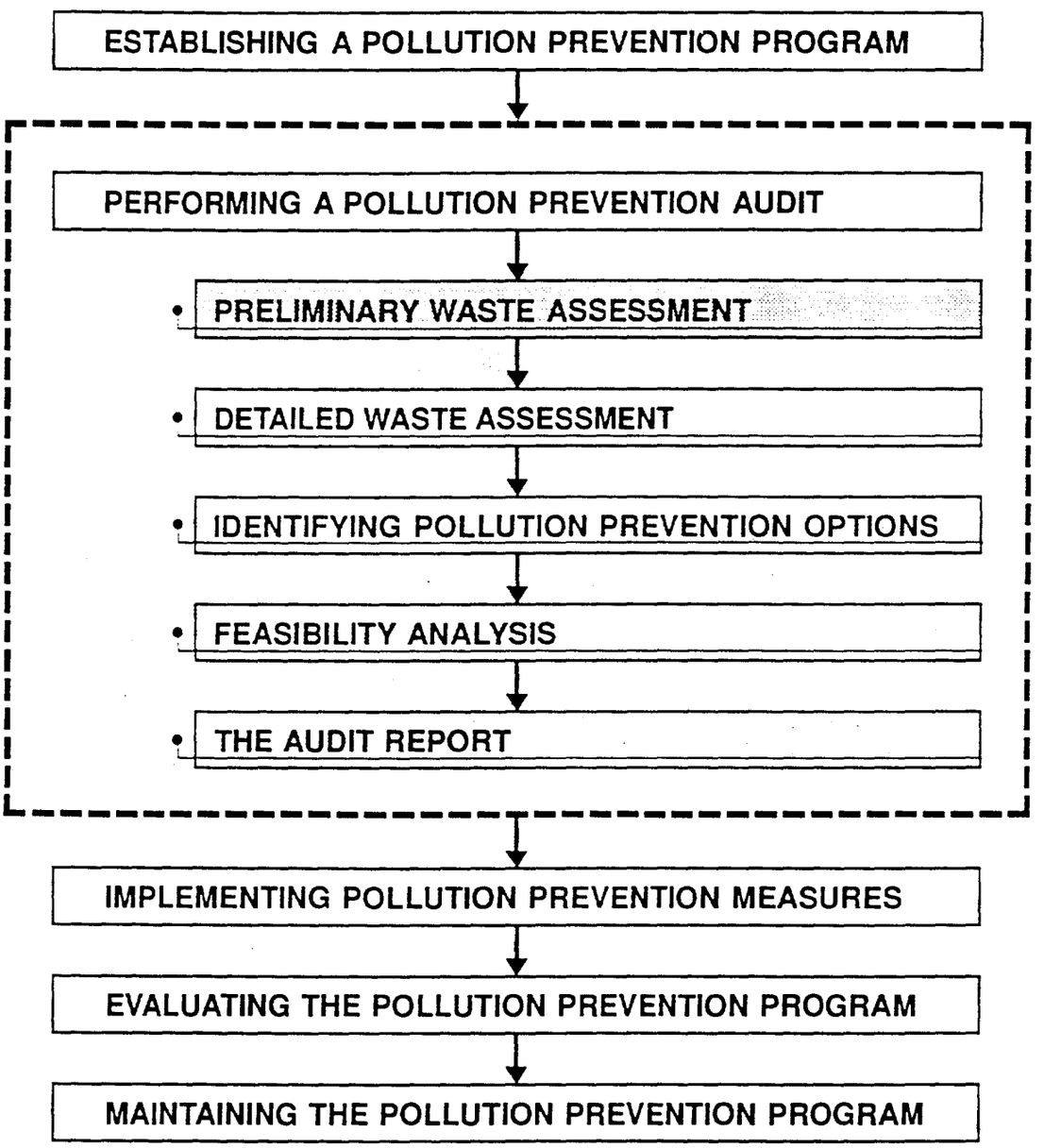
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IMPLEMENTING POLLUTION PREVENTION MEASURES
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MAINTAINING THE POLLUTION PREVENTION PROGRAM

PRELIMINARY WASTE ASSESSMENT

PURPOSE : Gain a basic understanding of each unit process and operation and their interrelationships within the whole manufacturing process.

- Conduct initial site survey
- Define objectives of the waste assessment
- Develop flow diagrams
- Develop an audit implementation plan

PRELIMINARY WASTE ASSESSMENT

CONDUCT INITIAL SITE SURVEY

- Organize the audit team to be made up of representatives from management, engineering, and plant operations
- Sketch drawings of processes, sewers, drains, vents and other material transfer areas
- Ask questions of foremen and operators about process and cleanup operations
- Collect available site drawings and operating data
- Identify data gaps

POSSIBLE SOURCES OF INFORMATION

• Raw materials use	- Purchasing records - Inventory records - Vendor information - Production logs - Discarded packaging material - Shipping and receiving logs - Annual report
• Waste generation	- Waste manifests - Sewer records - Permits / applications - Flow diagrams - Annual report - Rejected product - Environmental reports - Waste collection and storage - Production logs - Environmental violations - Laboratory analyses - Spill and leak reports
• Production	- Operations manuals - Vendor information - Control diagrams - Quality control guidebook - Production logs - Flow diagrams - Product specifications
• Process interrelationships	- Product-to-raw material data - Flow diagrams - Quality control data - Dependencies on other processes - Production logs - Product specifications - Facility layout
• Economic information	- Cost accounting reports - Costs for waste handling/disposal - Costs for materials, utilities, labor, etc. - Pollution control costs

PRELIMINARY WASTE ASSESSMENT

DEFINE OBJECTIVES FOR THE WASTE ASSESSMENT

- Specific unit processes or operations
- Areas of raw materials losses
- Wastes that cause processing problems
- Hazardous wastes
- Wastes with high disposal costs
- Wastes with high associated safety liability
- Wastes produced at high quantities
- Wastes with potential recovery of valuable by-products

USEPA'S HAZARDOUS WASTE REDUCTION PRIORTIES LIST

- Benzene
- Cadmium and cadmium compounds
- Carbon tetrachloride
- Chloroform
- Chromium and chromium compounds
- Cyanide and cyanide compounds
- Lead and lead compounds
- Mercury and mercury compounds
- Methyl chloride
- Methyl ethyl ketone
- Methyl isobutyl ketone
- Nickel and nikel compounds
- Tetrachloroethylene
- Toluene
- 1, 1, 1 - trichloroethane
- Trichloroethylene
- Xylenes

PRELIMINARY WASTE ASSESSMENT

DEVELOP FLOW DIAGRAMS

- Identify and list all unit processes and operations
- Summarize information in a flow diagram

UNIT PROCESSES AND OPERATIONS

UNIT PROCESS :

- An activity where material is input, a reaction occurs and materials are output in a different form, state, or composition

EXAMPLES :

- Fermentation
- Polymerization
- Adsorption
- Neutralization

UNIT OPERATION :

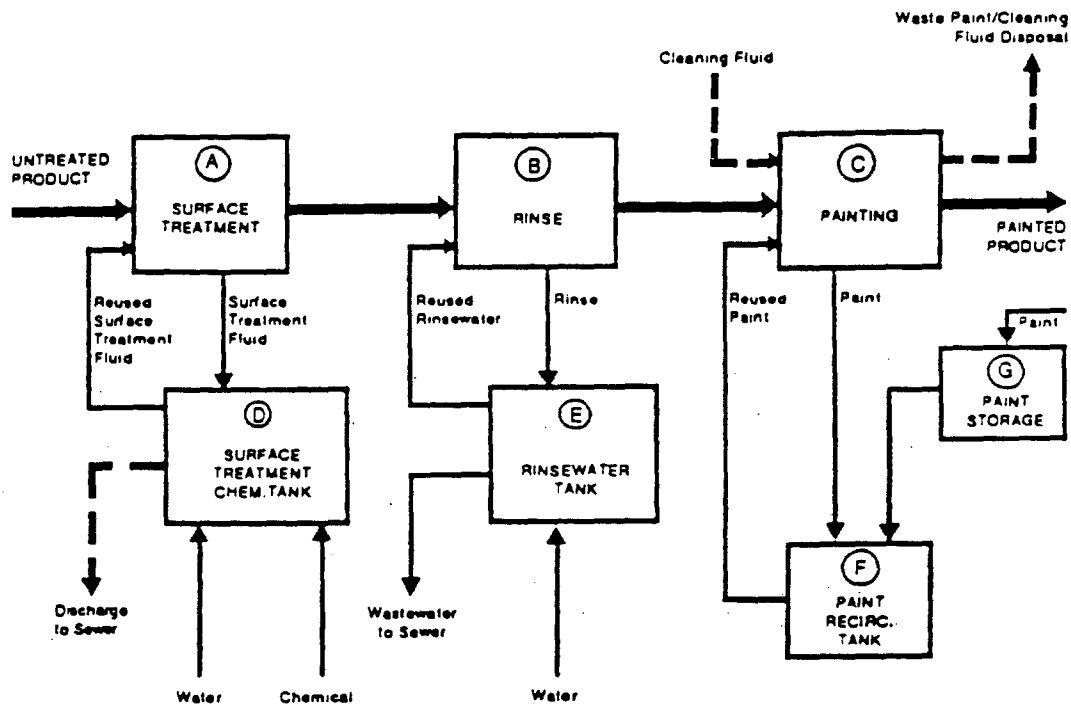
- An activity where materials are input, a function occurs and materials are output, possibly in a different form, state, or composition

EXAMPLES :

- Material storage
- Filtration
- Distillation
- Evaporation
- Heat transfer
- Crystallization

PRELIMINARY WASTE ASSESSMENT

A PROCESS FLOW DIAGRAM FOR A METAL FINISHING PROCESS



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HARZA

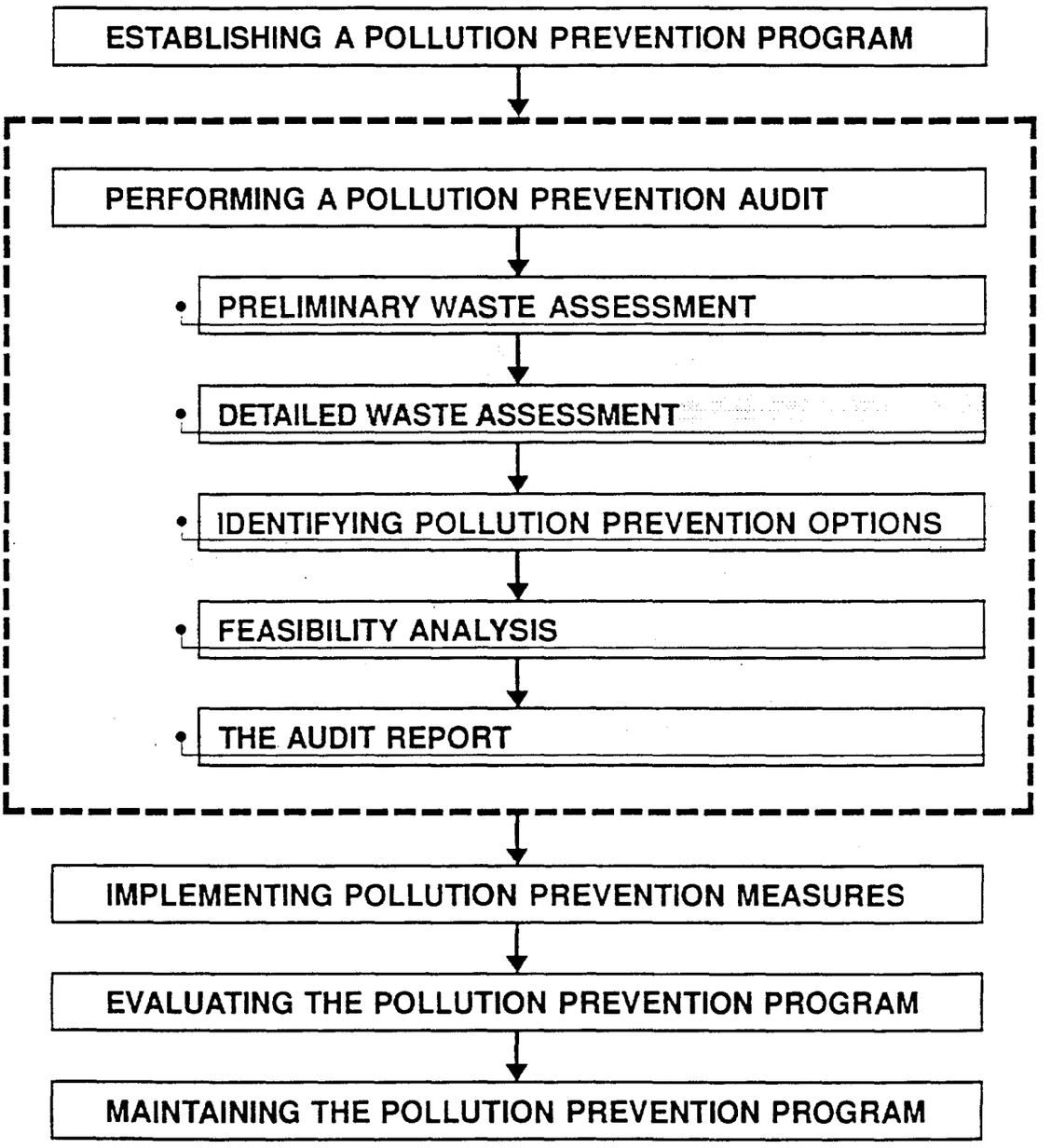
SOURCE: United Nations Industrial Development Organization, and United Nations Environment Program, Audit and Reduction Manual for Industrial Emissions and Wastes

DEVELOP AN AUDIT IMPLEMENTATION PLAN

- Delegate responsibilities within the audit
- Delegate responsibilities within the audit team
- Establish goals for the audit
- Devise a schedule
- Secure financial resources
- Locate supporting resources (laboratories, equipment, etc.)
- Organize the above into a complete audit implementation plan

DETAILED WASTE ASSESSMENT

75


ESTABLISHING A POLLUTION PREVENTION PROGRAM
PERFORMING A POLLUTION PREVENTION AUDIT
• PRELIMINARY WASTE ASSESSMENT
• DETAILED WASTE ASSESSMENT
• IDENTIFYING POLLUTION PREVENTION OPTIONS
• FEASIBILITY ANALYSIS
• THE AUDIT REPORT
IMPLEMENTING POLLUTION PREVENTION MEASURES
EVALUATING THE POLLUTION PREVENTION PROGRAM
MAINTAINING THE POLLUTION PREVENTION PROGRAM

DETAILED WASTE ASSESSMENT

PURPOSE : Inventory all mass inflows and outflows within the system in order to obtain a detailed material balance for revealing Pollution Prevention opportunities.

- Quantify process inputs
- Quantify process outputs
- Construct a material balance

QUANTIFY PROCESS INPUTS

- Water inputs
- Material inputs
- Air inputs

DETAILED WASTE ASSESSMENT

WATER INPUTS

- Identify water sources
- Review process manuals
- Understand process requirements
- Install meters or other flow measuring devices
- Review process input/output documentation
- Account for the effect of recycled water from other operations
- Determine methods of water transfer (pumps, gravity, manually)
- Estimate domestic water usage based on the number of employees at the site
- Conduct personnel interviews regarding operating habits

DETAILED WASTE ASSESSMENT

MATERIAL INPUTS

- Review raw materials inventory records
- Review chemical inventory and usage records
- Review reuse/recycle process records
- Review waste monitoring records
- Review permit information
- Review vendor information
- Observe discarded packaging material

DETAILED WASTE ASSESSMENT

AIR INPUTS

- Install monitoring equipment
- Review process records
- Review vendor information

DETAILED WASTE ASSESSMENT

QUANTIFY PROCESS OUTPUTS

- Product and by-products
- Wastewater
- Solid wastes
- Air emissions
- Reused and recycled wastes

DETAILED WASTE ASSESSMENT

PRODUCT AND BY-PRODUCTS

- Review production records
- Review sales records
- Review inventory records
- Review shipping and receiving logs
- Review annual reports

DETAILED WASTE ASSESSMENT

WASTEWATER

- Identify the effluent discharge points
- Identify where flows from unit operations contribute to the overall flow
- Design a sampling and flow measurement program
- Take samples over a range of operating conditions
- Analyze contaminant levels in the wastewater to determine water quality. (pH, BOD, COD, TSS metals, specific process wastes)

DETAILED WASTE ASSESSMENT

SOLID WASTES

- Review material inventory records
- Review disposal receipts
- Observe on-site waste storage practices

DETAILED WASTE ASSESSMENT

AIR EMISSIONS

- Monitor emissions
- Estimate emissions by calculations
- Identify emission characteristics by considering:
  - Odors associated with specific unit operations
  - Time trends for heavier emissions
  - Temperature trends
  - Pollution controls in existence

DETAILED WASTE ASSESSMENT

REUSED AND RECYCLED WASTES

- Measure and monitor current recirculation quantities
- Review process plans
- Determine combined flows

DETAILED WASTE ASSESSMENT

DEVELOP A MATERIAL BALANCE

- Standardize units of measurement
- Assemble the input and output information for each unit operation
- Include the measured values in the process flow diagram
- Use the general guideline that inputs equal outputs
- Use judgement based on non-quantitative information where data gaps exist

3.

PERFORMING A POLLUTION PREVENTION AUDIT

CASE STUDY 1: BEER PRODUCTION

Company A operates a modern brewery in western Europe, producing beer in bottles, kegs and bulk tankers. The essence of beer production is the processing and fermentation of malt and hops in the presence of added sugar. Considerable volumes of wastewater containing high BOD/ COD and suspended solids (SS) concentrations are produced as a result of washing of vessels and associated equipment between production batches.

Company A has been in operation some four years. During this time wastewater flows and pollution loads have increased significantly with production increases, resulting in consent limits for discharge to the public sewer (pH 6-10 and 500 mg/l SS) being exceeded on a regular basis.

The regional water authority recently indicated however that the brewery flows could continue to be accepted into the public sewer without pretreatment other than possibly pH control and flow/ load balancing at some future date, primary settlement and biological treatment being undertaken at an extended local municipal sewage treatment works.

The water authority also informed Company A that a capital cost contribution towards the planned sewage works' extensions would not be necessary and that the normal trade effluent charging system would be applied whereby charges varied according to variations in flow and pollution loads (COD and SS).

The current trade effluent charges amount to US$332,000 per annum and are expected to increase by 10% shortly. After considering the likely implications of the increase in effluent charges, the company decided to appoint a firm of consultants to carry out a waste audit and waste reduction study to investigate the possible ways of minimising waste disposal costs.

The following case study describes the waste audit/waste reduction procedures carried out.

PHASE 1: PREASSESSMENT

Step 1: Audit Focus and Preparation

Two chemists from the consulting firm's staff were allocated to carry out the required investigations, assisted as necessary by one of Company A's brewing technologists.

With the support of senior management, the audit team first organised an in-house seminar. This enabled the study procedures and objectives to be outlined and helped to ensure the full co-operation of production staff.

With the help of the brewery's engineering staff, a V-notch weir was then installed in a manhole where all the various effluents combined so that the flow could be monitored continuously using an available ultrasonic level/flow meter and associated chart recorder.

Since an automatic sampler was not readily available, it was decided that composite samples would be taken daily by combining manually-taken samples in proportion to flow. It was also established that the brewery's laboratory was well-equipped to carry out the required wastewater analyses.

In view of the scale of the brewery operations and the time and budget constraints imposed on the project, it was decided that the study should concentrate on:

- water usage aspects (rather than attempt to obtain a complete materials balance);
- investigate methods of reducing COD and SS loads discharging to drain.

In order to put the brewery operations in perspective from a waste management viewpoint, a preliminary check on wastewater and pollution loads discharged per cubic metre of beer produced was carried out based on past records of water usage and product data together with some limited information on combined wastewater strength.

It was concluded that, in general, the brewery operated with a very low degree of water wastage with most of the useful by-products or wastes already being recycled or recovered for off-site disposal. These aspects had been considered at an early stage in the design of the brewery and had clearly paid dividends in reducing waste volumes and pollution loads discharged. Nevertheless, it was considered that there was still scope for further waste saving measures to be implemented.

The success of the measures already practised can be illustrated as follows:

Table 1: Waste Contributions from Beer Production

	Company A	Typical Brewery (a)	Old Brewery (b)
Wastewater Flow (m^3/m^3 beer)	2	7	-
BOD Load (kg/m^3 beer)	4.1	4.5	7.5

(a) Based on the consulting firm's project experience elsewhere
(b) Based on data published by WHO, 1982

Another factor in favour of Company A is that most of the beer is transported from the brewery in road tankers rather than bottles or kegs, both of which give rise to more waste being produced. This simplifies the brewery operations and makes for more efficient and economical operation in terms of water consumption.

Step 2: Listing Unit Operations

The study team started off the waste audit/waste reduction programme by becoming familiar with all the various production stages. This was done by walking around the plant with the brewery technologist and collecting relevant information from departmental records. It was found that so much data were being collected that a file was opened for each key area within the brewery.

The various unit operations were listed as in Table 2.

Table 2: Major Unit Operations and Brief Functional Description

Unit Operation	Brief Functional Description	File No.
Brewhouse	Processing of malt, hops and sugar to produce 'wort'	1
Fermentation	Fermentation of chilled 'wort'	2
Product Treatment	Centrifugation, filtration, carbonation, colouring and final polishing and pasteurising	3
Dispatch	Bottling, kegging and bulk tanker filling	4

Step 3: Constructing Process Flow Diagrams

A schematic flow diagram was then compiled to illustrate the various unit operations within the brewery (Figure 1).

Once all the unit operations had been identified and described, the audit team proceeded to gather data on water usage, wastewater output and waste recovery.

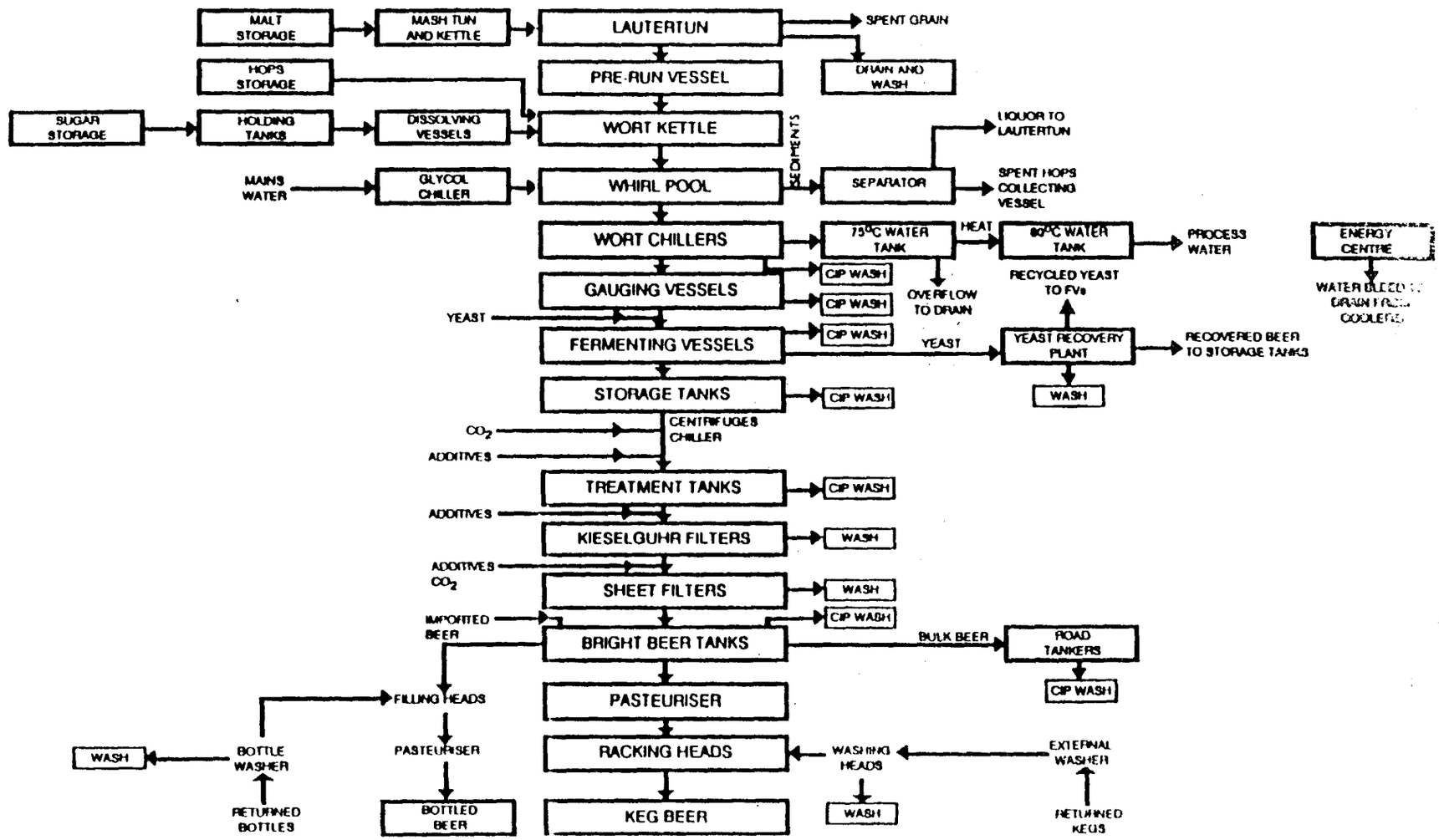


Figure 1: General

PHASE 2: MATERIAL BALANCE: PROCESS INPUTS AND OUTPUTS

Step 4: Determining Inputs

The audit team first proceeded to gather data on material inputs, concentrating on water usage, both for the brewery process as a whole and for individual unit operations. These activities are described further in Step 5.

Step 5: Recording Water Usage

The total water consumption from water meter readings for the previous three month period was found to be 247,500 m^3, equivalent to an average 2,750 m^3/d.

This included a small domestic water allowance, evaporation make-up and water entering the beer products as well as general washdown water for equipment for cleaning operations.

The audit team then proceeded to examine how water usage was split between the various unit operations.

Step 6: Measuring Current Levels of Waste Reuse/Recycling

No attempt to quantify the extent of current waste reuse/recycling was made during the waste audit programme since it was felt that this would have involved a considerable time input disproportionate to the likely benefits obtained.

However, it was noted that reuse of caustic and sterilant rinses following discharge to drain of initial water rinses generally formed an integral part of the automatic cleaning-in-place (CIP) system employed for equipment washing.

Step 7: Quantifying Process Outputs

The principal process outputs of concern were the wastewater discharges arising from production operations and also the beer products themselves.

It was also noted that minor domestic sewage contributions discharged to the same drainage network as the brewery process wastewaters.

The audit team then proceeded to quantify these outputs.

Step 8: Accounting for Wastewater

The total wastewater flow recorded during a two-week monitoring period averaged 1,730 m^3/d. It was noted, however, from the flow patterns during each day that wastewater discharges were extremely variable with a peak flow rate of up to 100 m^3/h occurring when a hot water tank overflow was discharged. On the basis of this and a number of other assumptions, the audit team estimated that the maximum flow on any one day could reach 2,600 m^3/d.

The corresponding combined wastewater pollution loads averaged 5,980 kg COD/d and 1,500 kg SS/d. These figures equated to waste quantities per cubic metre of beer produced of 2.1 m^3, 7.1 kg COD and 1.8 kg SS. Assuming an average COD:BOD ratio of 1.7, the corresponding BOD waste load was 4.2 kg/m^3 beer produced. These unit wastewater flow and BOD load contributions proved to be similar to the approximate estimates calculated in Step 1.

An estimate of domestic water usage and hence domestic sewage discharges to the trade effluent drainage system were also made, together with an assessment of the quantity of water entering the beer products. Calculations indicated that these additional outputs averaged a total of 850 m^3/d, of which only 10 m^3/d (140 employees at 70 litres per head per day) related to domestic sewage.

Studies were then carried out to develop a breakdown of the main process outputs (wastewater and product) for each key unit operation. This involved sampling and flow measurement of individual discharges around the brewery. Since the volume and composition of some of these discharges varied considerably with the type of beer produced, the survey was undertaken over several weeks to allow a realistic assessment of the situation to be made.

Step 9: Accounting for Gaseous Emissions

Gaseous emissions were not of particular concern in the context of the terms of reference drawn up by Company A for the study. However, it was noted that the brewery boilers were gas-fired and that boiler flue-gas emissions were discharged via a tall stack such that they were not likely to give rise to any concern.

It was noted that if control of alkaline wastewater discharges associated with use of caustic soda in the CIP systems proved to be necessary in the future (a possibility if alkaline waste discharges could not be controlled at source), then use of acidic flue-gas (a source of carbon dioxide) could be considered for this purpose.

The audit team also observed that pockets of carbon dioxide in the fermentation areas could cause problems of drowsiness amongst the brewing staff and that improved ventilation would help to ensure their general health and safety.

Step 10: Accounting for Off-Site Wastes

At the time of the survey, wastes produced for transportation and disposal off-site were limited to spent grain and hops generated in the brewhouse as by-products. These were disposed of off-site by a local farmer, for cattle food and as a soil conditioner respectively, at no cost to the brewery. Total quantities were estimated at some 25,000 tonnes (wet weight) per annum.

Step 11: Assembling Input and Output Information for Unit Operations

As previously indicated, the prime interest in this waste audit and reduction programme was to concentrate on the potential for reducing wastewater and associated pollution loads.

Hence, for the purposes of the project in question, the material balance was confined to consideration of water issues only.

Step 12: Deriving a Preliminary Material Balance for Unit Operations

It was decided to conduct a preliminary material balance for the brewery as a whole, based on water usage, before embarking on the more complicated step of obtaining a balance for each key unit operation. This was then constructed as set out in below.

Inputs	m^3/d
Water	2,750

↓

Overall Brewery Operations

↓

Outputs	m^3/d
Domestic Sewage	10
Product	840
Wastewater	1,730
Total	2,580

Step 13: Evaluating the Material Balance

The material balance with respect to overall water usage showed a remarkably good agreement, the average daily water input amounting to 6.6% above the daily water output assessed.

Although raw materials in the form of malt, hops, sugar, additives and other process chemicals - and also wastes disposed of off-site - had not been included in the balance, it was noted that these items are relatively small in the case of breweries where water is the dominant raw material used.

Step 14: Refining the Material Balance

On studying the data collated, it was observed that no allowance for evaporation had been included in the material balance and that, from the consultant's previous experience of brewery operations, evaporation alone could account for up to 5% of total water usage. This allowance therefore effectively closed the small difference between water input and output indicated in Step 13.

The waste audit team then proceeded to build up material balances for all the major unit operations within the brewery. When this work had been completed, they felt that they had gained considerable knowledge about the various production activities, their inputs, outputs, wastes and operational problems.

PHASE 3: SYNTHESIS

Step 15: Examining Obvious Waste Reduction Measures

The audit team considered that the cost of wastewater disposal at the brewery could be minimised in two ways:

- reduction in volume, BOD* and/or SS load of the wastewater produced in the brewery;
- reduction in the BOD* and/or SS load of the wastewater discharged to sewer by pretreatment.

(* or rather COD, as used in the water authority's charging formula)

In the light of a comprehensive examination of the waste producing areas, it was possible to study both these alternatives. To assist the investigations into waste saving possibilities, reference was made to available information (including database) sources, as well as the consultant's own experience of undertaking similar projects.

The various sections of the brewhouse were studied in turn as follows.

a) Brewhouse

The two principal discharges in the brewhouse were the drain from the Lautertuns and a 75°C hot water tank overflow. Together these contributed 12% of the total wastewater flow from the brewery.

Study of the flow and analytical data obtained indicated that the Lautertun drain contributed 3.5% of the flow, 23% of the COD and 4% of the SS load. Discussions with the company indicated that it should be possible to store this waste flow for use as make-up water for the subsequent brew and that this should be possible without detriment to brewing standards. A 15 m^3 stainless-steel storage tank with associated pumps, valves and pipework would need to be installed with the advantage that the system would:

- reduce raw water costs;
- eliminate effluent charges previously incurred by this discharge;
- reduce energy requirements since the liquor returned as make-up water would not need heating;
- eliminate existing shock load discharges from this source which should remove any need for flow/load balancing of the total site wastewater flow.

The hot water tank overflow accounted for nearly 9% of the total wastewater flow. Since this water was clean and hot, continual reuse was the obvious possibility. Unfortunately this proved to be impossible owing to the spasmotic production of this water.

[illegible] to be impossible owing to the spasmotic production of [illegible]. As the 75°C tank was very large however, it was considered that its inherent [illegible] capacity could be utilised if the supply for reuse was taken part way down the tank rather than from the overflow when it occurred.

Reuse of this water would be preferable in a process that consumed hot water at approximately the same rate as the 75°C hot water production, that is 150 m^3/d. The only process in the brewery which utilised this quantity of hot water was the pasteurising machine which had a water consumption of some 170 m^3/d. However, all of this flow was not hot water since a temperature gradient had to be maintained within the pasteuriser to ensure that bottles were not warmed up or cooled down too rapidly.

It was considered that the 75°C hot water should be injected directly into the pasteuriser to replace the heating of cold water to 60°C. In addition, the hot water could be blended with the supply of cold water that already existed to give the required temperature profile thoughout the pasteuriser. It was estimated that such a system would enable at least 75 m^3 of the excess hot water to be reused each day.

b) *Fermentation Cellar*

The majority of waste produced in this area of the brewery originated from the CIP systems, the discharges from which contained a high COD load due principally to the high yeast content. With the exception of the initial rinse from pre-fermentation stage gauging vessels, the initial rinses from other tanks - fermentation tanks, storage vessels and yeast recovery vessels - all exceeded 6,000 mg/l COD and together accounted for over 90% of the COD load produced in the fermentation cellar.

Proposals for reducing/treating these discharges were developed as follows.

Gauging Vessels

Possibilities for reducing the pollution load from this source of CIP effluent were limited as no yeast was present which could be filtered out. However, reuse of the relatively-clean final rinse as the initial rinse for the next CIP wash would reduce the effluent flow to drain by a total of 26 m^3/d from 8 vessels.

It was also noted that the caustic wash from the brewhouse which occurred usually every week was discharged to drain from these gauging vessels every weekend and that this, together with the acid wash from Wort Kettle No.2 discharged via a fermentation (balancing) tank, had a major effect on the combined wastewater pH giving values frequently outside the allowable pH range for discharge to the public sewer of 6-10.

Tests showed that if the acid and caustic discharges were run to drain together, the neutralising effect of the acid on the caustic was neglible owing to the different volumes, strengths and

neutralise the predominant caustic load, it was envisaged that closing up the system by providing additional holding tank capacity would be suitable. This could be achieved using a similar arrangement to the existing closed CIP units in order to standardise on equipment; it would reduce effluent flows to drain, raw water costs and also chemical-cleaning costs.

Fermentation Tanks

The load produced by the initial rinse was found to be 210 kg COD/d and 150 kg SS/d which could be reduced by at least 75% by passing the rinse through a yeast press. It was considered that the final CIP rinse could also be reused as the initial rinse, reducing effluent flow by 25 m^3/d from 8 tanks.

As referred to above, acid washes from the brewhouse were being discharged from the fermentation tanks; on occasions, these depressed the pH to 2.4. Containment and recirculation via a new CIP unit was considered to be the most suitable and practicable control measure.

Storage Tanks

The initial rinse in the CIP sequence was found to contain 75 kg COD/d and 10 kg SS/d. It was estimated that passing these rinses through a yeast press would reduce overall loads from this source to 22 kg COD/d and 3 kg SS/d. Also, reuse of the final rinse as the initial rinse of the next sequence would reduce effluent flows by 5 m^3/d.

Yeast Recovery Plant

Discharges from centrifuge cleaning were difficult to arrange at the time of the waste audit and reduction investigations. However, from visual observations the initial rinse clearly contained a significant quantity of yeast and so it was recommended that such wastes should also be passed to a yeast filter press. Similarly, recovery of the final rinse and reuse as a subsequent initial rinse was proposed. It was also suggested that the initial rinses from yeast storage vessels should be filtered through a yeast press.

Company A had already purchased a new yeast press to filter yeast liquors which at the time were stored until press capacity became available. This proposal was expected to reduce storage requirements, allowing a small amount of beer recovery (press filtrate) and elimination of the frequent storage tank overflow.

Therefore, instead of treating each of the fermentation cellar discharges separately which would be uneconomic, the audit team considered that the proposed filter-press installation for the yeast recovery area should be arranged to filter the initial rinses from fermentation tanks, storage vessels and yeast recovery equipment. This would not only prevent the majority of yeast from flowing to drain but would enable its recovery for resale to a food manufacturer.

[illegible] any other liquor containing yeast that had to be dumped [illegible] from the storage tanks when the yeast storage vessels were full, would be filtered and the yeast and beer recovered. The expected increase in flow to the proposed filter press was estimated at 50 m^3/d containing 100 kg SS/d, well within the unit's design capacity.

c) *Treatment: Cellar*

A number of waste saving options were recommended for this area. The principal measures proposed related to the bottling and kegging areas. The possibilities of utilising the 75°C hot water tank overflow for the pasteuriser supply have already been highlighted in the brewhouse section above. The audit team felt that the water flowing out of the pasteuriser could be used as an initial rinse in the bottle washer.

The existing bottle washer system used 9 m^3/h fresh deionised water. It was proposed that the final sparge pipes should continue to be supplied with deionised water but that the pasteuriser water be used to supply the remainder and also for continual replenishment of the water in the final rinse tank. Mains water would be provided as a standby supply in the event for any reason that the pasteuriser water ceased.

In the kegging area, dumping of returned beer to drain was occurring periodically giving a very significant rise in BOD and COD load during the dumping periods. It was indicated to the company that separate disposal, possibility directly to land, should be seriously considered as often adopted by other breweries. It was noted, however, that this would require the permission of Customs and Excise officials and be subject to the beer being destroyed in an approved manner such as by dyeing.

Step 16: Targetting and Characterizing Problem Wastes

Following completion of Step 15, the audit team realised that significant reductions in wastewater flows and pollution loads could be achieved by carrying out all the improvement measures highlighted, all of which were relatively straightforward to implement.

It was decided it would be useful to obtain an overall picture of the waste savings which could be achieved. Thus, a summary of the existing and proposed reduced waste contributions for the unit operations highlighted in Step 15 was drawn up as presented in Table 3. At this stage, no allowance was made for the benefits of avoiding returned beer being discharged to drain since this was dependent on future discussions with Customs and Excise personnel.

Table 3: Summary of Existing and Proposed Reduced Waste Contributions

Unit Operation	Waste Description	Existing Composition			Recommendation	Predicted Composition		
		m^3	kg COD	kg SS		m^3	kg COD	kg SS
Lautertun	Final run to Drain	60	1392	60	Reuse	0	0	0
75°C Hot Water Tank	Overflow	150	-	-	50% reuse as make-up for pasteuriser	75	0	0
Brewhouse Vessels	Caustic and acidic wash at weekends	36	152	16	Installation of CIP unit	0	0	0
Gauging Vessels	CIP wash	26	-	-	Reuse rinsewater	0	0	0
Fermenting Vessels	CIP wash	65	248	188	Reuse and yeast separation	40	62	44
Storage Tanks	CIP wash	17	89	13	Reuse of rinsewaters and pressing of initial rinse	12	22	3
Yeast Storage and recovery	CIP wash	2	17	1	Yeast recovery	2	4	0.2
Pasteuriser	Process water	100	-	-	Reuse in bottlewasher	0	0	0
Total		456	1898	278		129	88	47.2

For flow, COD and SS load savings of 327 m^3/d, 1,810 kg COD/d and 230 kg SS/d (ref. Table 3), the predicted reductions on the total wastewater discharges assessed in Step 8 were approximately 19%, 30% and 15% respectively.

Step 17: Segregation

In formulating a series of recommendations for waste reuse and recovery which could be implemented relatively quickly (ref. Step 16), the waste audit team had recognised at an early stage that waste segregation would form an integral part of the waste reduction strategy.

The proposals were discussed with the management who, in principle, were in agreement that the various measures put forward were sensible and practicable, subject to the audit team being able to demonstrate that the likely long-term cost savings to be achieved would be appreciable.

Step 18: Developing Long-Term Waste Reduction Options

Prior to the water authority stating that the increase in local sewage treatment works capacity would not require a capital contribution from Company A, the brewery's waste management consultants had prepared preliminary plans for an on-site pretreatment plant based on pH control, balancing and oxygen activated sludge treatment.

This compact treatment option had been selected in view of the limited spare land area available on site. An additional attraction was the reduced risk of developing filamentous, poorly-settling sludges compared with conventional air activated sludge systems treating brewery, or similar wastes, having a high soluble carbohydrate content.

However, in the light of the water authority's subsequent proposals and a comparative economic assessment of the two alternatives - discharge of untreated combined wastewaters (or, at worst, following preliminary treatment only) plus payment of trade effluent charges, or partial biological pretreatment plus payment of reduced trade effluent charges - plans for pretreatment facilities on-site were shelved pending the outcome of the waste audit and reduction investigations.

The audit team considered that if the good housekeeping measures as outlined in Step 16 were implemented, particularly those relating to the reuse of the significant pollution load associated with the Lautertun drain and the control of caustic and acidic discharges, then future pH control and flow/load balancing of combined flows in order to ensure compliance with discharge standards would not be necessary.

Step 19: Environmental and Economic Evaluation of Waste Reduction Options

From the waste saving studies which were orientated around possibilities for reuse/recycling and recovery, it was clear that following implementation of the measures drawn up the net discharge of wastes to the environment would be significantly reduced. Thus, there would be a clear environmental benefit.

The audit team then tabulated the estimated trade effluent charges with and without allowance for the proposed waste saving measures (Table 4). This enabled the potential savings in these charges to be identified.

Table 4: [illegible] Charges

Unit Operation	Waste Description	Estimated Current Charges US$/annum	Estimated Reduced Charges US$/annum	Estimated Savings in Charges US$/annum
Lautertun	Final run to drain	58,000	0	58,000
75° Hot Water Tank	Overflow	7,000	3,500	3,500
Brewhouse Vessels	Caustic and Acidic Wash at Weekends	7,800	0	7,800
Gauging Vessels	CIP Wash	1,200	0	1,200
Fermenting Vessels	CIP Wash	25,000	7,000	18,000
Storage Tanks	CIP Wash	5,000	1,500	3,500
Yeast Storage and Recovery	CIP Wash	800	200	600
Paustenser	Process Water	4,300	0	4,300
Total		109,100	12,200	96,900

The trade effluent charges listed in Table 4 were then compared with the expected total trade effluent charge for the existing combined wastewaters, estimated at US$365,000 per annum for the forthcoming year. This indicated a 26% reduction resulting from implementation of the flow/load reduction proposals.

Based on the data set out for Step 16, the reduced average flows and loads would be some 1,400 m^3/d, 4,170 kg COD/d and 1,270 kg SS/d. This corresponded to reduced average waste quantities per cubic metre of beer produced of 1.7 m^3, 5.0 kg COD and 1.5 kg SS.

Further examination of all the waste audit data obtained indicated that peak wastewater flows and loads on any one production day could rise to 70% above these average discharge levels. However, the assessment of trade effluent charges based on average discharges was considered to give a realistic estimate of the savings which could be expected over a full production year.

The audit team appreciated that in addition to savings in trade effluent charges, there would be other cost benefits which were difficult to quantify during the time-frame of the consultant's brief but which included costs associated with raw water, energy and the probable elimination of combined wastewater treatment which would otherwise be required to meet discharge consent conditions consistently.

It was also recognised that some capital expenditure would be required to implement the proposed waste reduction programme. It was agreed with the brewery management that this aspect was best costed by their own engineering staff but that since the capital sums involved would be relatively small compared to the company's capital expenditure budget for the current year, and related to progressive improvements in the brewery production operations, the company would be likely to accept the waste savings proposals on the basis of the significantly reduced trade effluent charge savings alone.

Step 20: Developing and Implementing an Action Plan: Reducing Wastes and Increasing Production Efficiency

The results of the waste audit and waste reduction studies were formally presented to Company A's management in the form of a technical report. The recommendations made were accepted and plans were then made to implement the recommendations.

The waste audit had provided a sound understanding of all principal sources of waste arising within the brewery. Furthermore, the brewery technologist assigned to assist the waste audit team had benefitted greatly from being involved in the step-by-step approach adopted by the company's consultants.

It was considered that the experience gained by the brewery would enable company staff to take the lead in any future waste audit programme, particularly the assessment of the actual waste reductions achieved following commissioning of the plant modifications and additions proposed.

Case Study 2: Steel pickling

Autonut Limited, a manufacturer of nuts and bolts for the automobile industry, purchases 25,000 tonnes per year of rod steel from a local steel mill. The rod steel is machined into nuts and bolts in a series of processes. Steel develops a surface coating of oxidized iron, called scale or rust, which must be removed before machining begins. This rust and scale is traditionally removed by chemically reacting steel with sulphuric acid (H_2SO_4) or hydrochloric (HCl) acid, a process called pickling.

In the pickling process, steel is immersed in an acid bath which dissolves the scale and some of the iron. The steel is then removed from the bath and the acid is rinsed off. The steel then receives selected coatings and continues through the manufacturing process. Pickling causes an increase in the iron content of the acid which reduces pickling efficiency. Fresh acid must be added to the bath to maintain an efficient reaction rate.

Eventually, the iron content becomes too high for effective pickling and the spent pickle liquor must be replaced with fresh acid. Sludge which has settled to the bottom of the pickling tank must also be removed. Disposal of this spent pickle liquor, sludge and pickling rinsewaters creates a potential pollution problem.

Autonut had installed a high speed sulphuric acid batch pickling line in 1980. However, since the process was commissioned, environmental control regulations had tightened considerably. As a result, the company faced confrontations with regulatory authorities on air and water pollution as a result of acidic air emissions and discharges of high iron content and acidic rinsewaters which exceeded municipal by-law levels. As well Autonut paid about $380,000 annually for haulage and disposal of the spent pickle liquor.

Costs of fresh acid, water, electricity and labour were also increasing and the company wanted to increase its production capability.

What was the best and most cost effective solution to these problems? The company started off on the right track by conducting an in-plant study or waste audit of its pickling and waste treatment operations. As you will see, the company adopted a waste reduction strategy and increased its production efficiency while resolving pollution problems resulting from fumes and wastewater and it eliminated the expense of waste acid disposal.

Following is a description of the approach taken. Autonut management appointed a senior engineer to organize a team of employees to carry out the waste audit and subsequent waste reduction plan. The team consisted of the engineer, the pickling supervisor and a chemical technician. All other employees were made aware of the importance of the work through a newsletter and regular bulletins.

Phase One: Understanding the processes in your plant

Step 1: Listing of unit processes

The engineer started off the study by walking around the pickling and waste treatment facilities, listing all the unit processes and making notes of their respective functions and use. He solicited opinions and assessments from all the plant supervisors who were familiar with the day to day operations. The unit operations are listed in Table 1. Extensive observations on how the units were operated were also recorded.

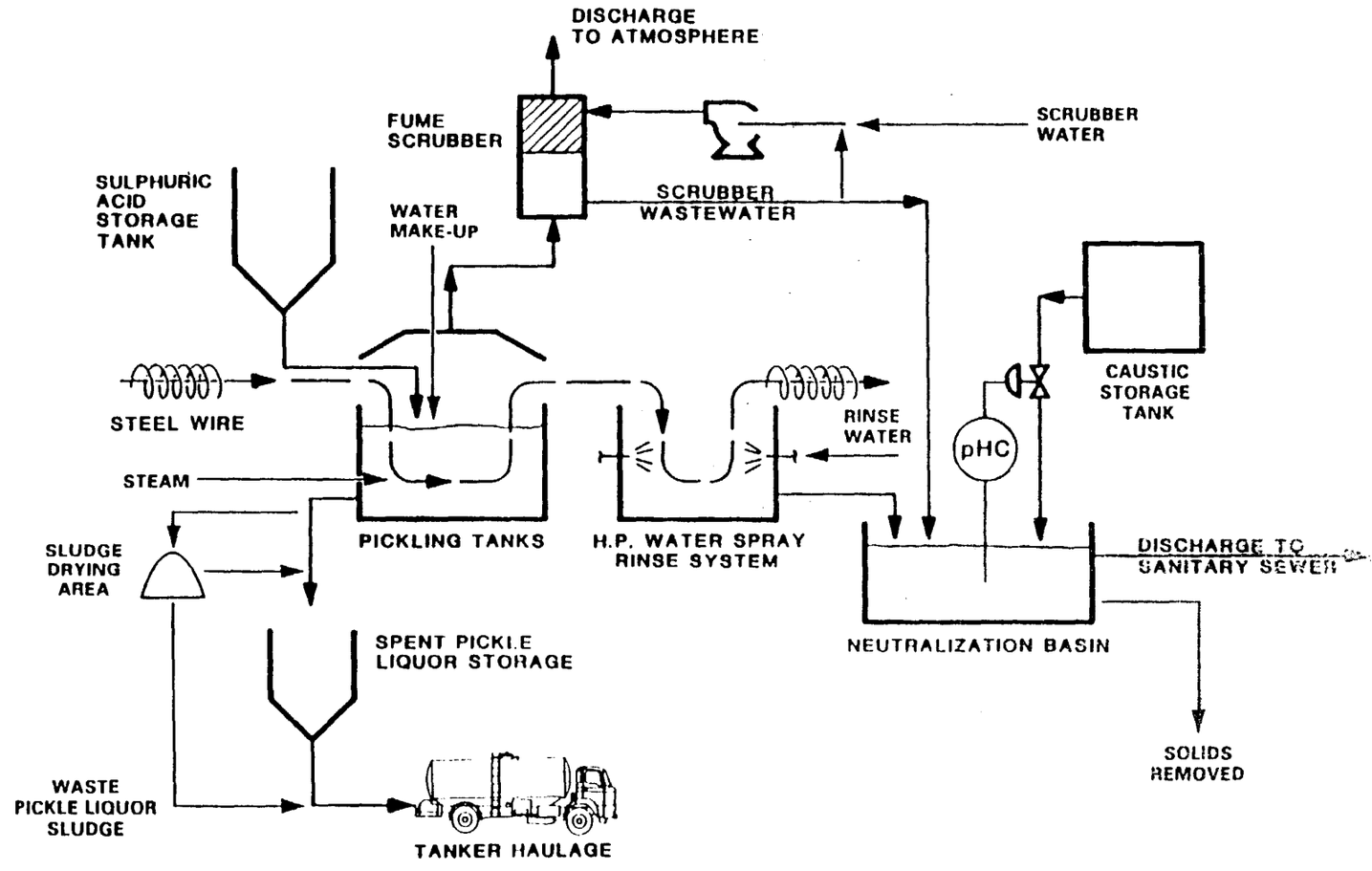
Table 1: Listing of Unit Processes

Unit Process	*Functional Description*
Pickle Tanks (2)	17.5 m^3, steel, rubber lined
High Pressure Spray Rinse Tank	30 spray rinse nozzles, supplied by 1000 L/min pump
Fume Scrubber	Packed bed wet scrubber with internal recycle
Storage Tank for 50% Caustic Soda	Bulk storage (20 m^3)
Neutralization Basin	Basin with rudimentary solids removal

In order to address the most pressing air and water pollution problems and the costly disposal of spent pickle liquor, the team agreed to focus the waste reduction audit on the following operations: pickling tanks, spray rinsing, fume scrubber and wastewater treatment. However, studies of other operations, (e.g. surface coating and steam generation) could also pinpoint additional areas of wastage and losses.

Step 2: Constructing a process flow diagram.

A flow diagram was then prepared to illustrate the interrelationship of all the unit processes (Figure 1). The engineer presented this process flow diagram to the team.


DISCHARGE
TO ATMOSPHERE
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SCRUBBER
SCRUBBER
WATER
SULPHURIC
ACID
STORAGE
TANK
WATER
MAKE-UP
SCRUBBER
WASTEWATER
CAUSTIC
STORAGE
TANK
STEEL WIRE
RINSE
WATER
pHC
STEAM
PICKLING TANKS
H.P. WATER SPRAY
RINSE SYSTEM
DISCHARGE TO
SANITARY SEWER
SLUDGE
DRYING
AREA
NEUTRALIZATION BASIN
SPENT PICKLE
LIQUOR STORAGE
SOLIDS
REMOVED
WASTE
PICKLE LIQUOR
SLUDGE
TANKER HAULAGE

Step 3: Determining resource usage

The waste reduction audit team assigned the engineer and chemical technician to determine the annual flow rates and the compositions of the inputs and outputs. They drew up a table listing the annual consumption of all the raw materials used (Table 2). The sulphuric acid was purchased at a concentration of 93%. The caustic was 50% sodium hydroxide. Since acid and caustic was also used by other areas in the plant, purchasing records could not be used to estimate annual consumption. Therefore, usage of acid and caustic in the pickling plant was measured during a typical production week and extrapolated for the full year.

To simplify matters the engineer estimated that the annual purchase of steel rod consisted of 24,750 tonnes iron (ignoring the fact that steel contains other elements as well) and 250 tonnes of FeO (to average out the iron and various iron oxide components in the rust and scale).

Table 2: Annual usage of raw materials

	Annual Raw Material Usage (all tonnes per year expressed as t/a)		
Unit Process	*Sulphuric Acid (93%)*	*Rod Steel*	*Caustic (50%)*
Pickling	660	25,000	-
High Pressure Rinsing	-	-	-
Fume Scrubber	-	-	-
Neutralization Basin	-	-	106

Step 4: Raw material storage and handling losses.

Due to the nature of the two major raw materials, steel and sulphuric acid, it was considered that no significant handling losses were occurring. However, company records did seem to indicate that length of storage time for the steel might have an effect on the actual pickling times required, probably due to increased rust formation. As part of the audit the waste reduction team undertook to measure the weight loss during pickling of samples stored for different lengths of time.

Step 5: Recording water [illegible]

The next step was to account for the w[illegible] pickling plant. The total water consumption in the [illegible] was recorded at 29,700 m³ per year (equivalent to tonnes per year). The water was used for the baths, make up, rinsing, steam production and clean-up.

Flow measurements of the spray rinsewaters indicated that most of the water consumption was for rinsing only. The engineer observed the spray rinse system in operation and made a note that this was a definite area for waste reduction.

The engineer observed the pickling tanks in operation on several occasions and noted that the live steam injection (direct injection of steam into the pickling tank) which was being used for heating and agitating the pickling bath did not seem to be giving uniform and thorough agitation to the acid solution. This could affect the efficiency of the pickling process.

The water was consumed as follows:

Table 3: Water Consumption

Use	*Quantity Used m³/yr*
Make up water in the pickling tank	1,702
Steam generation	1,600
Water used to rinse the steel	24,300
Scrubber water	900
Total water consumption	29,700

Step 6: Measuring current levels of waste reuse.

It was noted that no wastes were reused at the pickling plant.

Steps 3 to 6 were concerned with the inputs to the pickling plant and wastewater treatment. Steps 7 to 9 are now concerned with defining the outputs from these operations.

Phase Three: Defining Process Outputs

Step 7: Identifying process outputs.

The engineer and chemical technician also drew up a list of outputs which included product, intermediate flows within the pickling plant, airborne emissions, wastewater sewered and wastes which were hauled away for off-site disposal. All the process outputs were recorded in Table 4. The amount of descaled rod steel produced was easy to determine from production records. Steps 8 and 9 discuss how the wastewater and wastes were determined.

Table 4: Process outputs

Unit Process	*Product*	*Waste Reused*	*Airborne Waste*	*Wastewater Sewered*	*Liquid Waste*	*Solid Waste*
Pickling liquor	De-scaled rod steel (24,750 t/a)	-	Evaporation and acid fumes	- liquor	Spent pickle sludge	Pickle
High Pressure Rinsing	Cleaned rod steel	-	-	24,300 t/a	-	-
Fume Scrubber	High pH waste-water to treatment	-	Evaporation	900 t/a	-	-
Neutralization Basin	Dischargeable wastewater	-	-	27,000 t/a[1]	-	(small quantity)

[1] Includes the spray rinse wastewater.

Step 8: Accounting for wastewater flows.

All wastewaters discharged to the sanitary sewer from the pickling and rinsing operations were pH adjusted. The wastewater discharged to the sanitary sewer was analyzed and the flowrate was measured. Of the 27,000 m^3/annum discharged, 24,300 m^3/annum was from the rinsing operations.

Records of wastewater discharged to the sanitary sewer indicated that the pH of the effluent was subject to periods of overdosing and under-dosing of caustic. In addition, the public works authorities were concerned with the large amounts of iron hydroxide being discharged and were threatening to prosecute Autonut for violations of the sewer use by-law.

Step 9: Documenting wastes stored and hauled off-site for disposal.

According to waste disposal records, 2,191 t/a of spent pickle liquor was disposed of at a local oil recovery facility at cost of $361,000 per year. In addition when the pickle tanks were pumped out, considerable sludge (100 t/a) was found in the bottom of the tanks. This sludge (ferrous sulphate) was shovelled into containers and dumped in a sludge drying area, allowed to drain and then hauled off-site to disposal. The quantities of waste hauled off-site to disposal are recorded in Table 4.

Operators added acid as they observed that pickling rates were decreasing. The iron concentration was monitored and when it reached 7% iron by weight, acid was no longer added and the whole bath was dumped.

An old analysis of one spent pickle liquor bath determined that the free acid content was 4 percent H_2SO_4. One shipment of the pickle liquor sludge had also been analyzed. The iron content was determined to be 25 percent and the total sulphate was 31percent.

The engineer checked Autom[illegible] records and confirmed the classification of the [illegible] hazardous waste, having a waste classification [illegible] designation described its primary characteristics [illegible] other liquid or solid wastes were registerable under O. Reg. [illegible] the Environmental Protection Act.

Phase Four: Material Balance Study

Step 10: Listing of process input and output information.

Using the basic mass balance principal of "what goes in, must come out" the engineer decided to list all the input and output information in order to determine the adequacy of the information already accumulated.

The team drew up a list of the inputs and outputs (Table 5) and decided what parameters were important for each input/output. In addition to the total quantities, the team realized it would be necessary to track the major chemical constituents, total sulphate and iron. Tracking the sulphate ion was important because it indicated the consumption of a primary raw material, namely sulphuric acid. Iron was also important because it was the major contaminant of the waste streams and its concentration in the wastewater was above the sewer-use by-law. The team used the compositions of each input/ouput, as determined in Steps 3 to 9, in order to obtain the sulphate and iron quantities in each stream.

The team considered iron loss from the steel rods to be an input to the process. Iron in the steel rods which passed through the pickling process, was not listed as either an input or an output since the large quantity would mask variations in other outputs of iron, such as wastewater and wastes sent for disposal.

To determine the annual iron loss from the unpickled steel, the engineer determined the average weight loss of a variety of samples during the pickling process. Iron loss is made up of scale removed and base metal dissolved, a mixture of iron (Fe) and iron oxides (FeO). The 250 tonnes of iron loss from the steel rod was listed as the input to the process.

The rinsewater was sampled and analyzed for sulphate and iron. From this result, the dragout of pickle liquor could be calculated. The rate of evaporation was determined by measuring the change in level of solution in the pickle tank and subtracting the dragout rate.

Table 5: Process Inputs and Outputs

Pickling process

Inputs	Total (t/a)	Sulphate SO_4 (t/a)	Iron Fe (t/a)
Iron loss	250		194
Sulphuric acid feed (93%)	660	601	
Water (make up in the pickling tank)	1,702		
Steam	1,600		
Outputs	**Total (t/a)**	**Sulphate SO_4 (t/a)**	**Iron Fe (t/a)**
Dragout (from pickling)	275	60	19
Evaporation	1,125		
Spent pickle liquor	2,191	349	153
Pickle liquor sludge	100	34	25

Neutralization Basin

Inputs	Total (t/a)	Sulphate SO_4 (t/a)	Iron Fe (t/a)
Rinsewater	24,325	60	19
Scrubber wastewater	900		
Caustic soda	106		
Outputs	**Total (t/a)**	**Sulphate SO_4 (t/a)**	**Iron Fe (t/a)**
Discharge to sewer	27,000	68	23
Solids			

Step 11: Deriving preliminary material balances.

Preliminary material balances were then constructed for the pickling process and neutralization basin as in Figures 2 and 3.

Figure 2: Preliminary material balances on the pickling process.

Inputs	Total (t/a)	Sulphate SO_4 (t/a)	Iron Loss Fe (t/a)
Iron loss	250		194
Sulphuric acid feed	660	601	
Make up water in the pickling tank	1,702		
Steam	1,600		
Total	4,212	601	194

▼

Pickling Process

▼

Outputs	Total (t/a)	Sulphate SO_4 (t/a)	Iron Loss Fe (t/a)
Dragout (from pickling)	275	60	19
Evaporation	1,125		
Spent pickle liquor	2,191	349	153
Pickle liquor sludge	100	34	25
Total	3,691	421	197

...ious waste reduction measures.

...data was organized by the engineer and presented to the waste reduction audit team. Over the course of a couple of sessions, the team brainstormed to arrive at practical alternatives to reduce the following waste streams:

- spent pickle liquor
- pickle liquor sludge
- spray rinsewater
- pickling tank fumes

Spent pickle liquor and sludge are inevitable wastes from the existing pickling system. The team determined that the pickling process could be optimized to lower the concentration of free acid and that improved inventory control of steel rod would reduce rust formation. Both of these actions would contribute only a small reduction in the volume of spent pickle liquor. As a result they were given a low priority. However, the existing method of rinsing the rod steel using automatic high pressure sprays at about 1,000 litres per tonne of steel was an obvious and large source of waste.

It was noted that a high level of pickling bath "drag-out" was occurring and that the high pressure sprays were particularly inefficient. As a result, significant quantity of acid was being lost from the system and large quantities of acidic wastewater required pH adjustment before discharge to the sewer. This was another obvious area for waste reduction.

During the brainstorming sessions, the team agreed that best method to reduce the rinsewater wastage was through counter-current rinsing of the steel. In addition, it was agreed that steam agitation should be replaced with air agitation. Heating would be accomplished by installing an external heat exchanger. The engineer and the pickling plant supervisor were assigned to work out the details of these plans.

The engineer found that one of the least expensive techniques for counter-current rinsing after batch pickling was to use the dip and spray system. After dipping in the rinse tank, the work is held over the tank and a spray of fresh water is then activated and applied to the work to remove the slightly contaminated rinsewater remaining on the steel. This slightly contaminated rinsewater is then collected in the rinse tank.

This method would reduce the rinsewater requirement from an inefficient 1,000 litres per tonne of steel to less than 100 litres per tonne. In this manner, very significant savings in rinsewater consumption would be achieved.

Furthermore, by changing the method of agitation and heating, the pickling bath would have a negative water balance: that is, water would be lost from the pickling tank by evaporation instead of being introduced by the condensation of steam. As a result, the sulphuric acid would not be diluted. In addition, the dilute acid solution from a counter-current rinsing system could be balanced with the evaporation rate and used as make-up volumes in the pickling tank, thereby reusing acid and completely eliminating the rinsewater discharge.

The air agitation system would also increase pickling efficiency by improving mixing, and would increase evaporation from the pickling tank. The pickling plant supervisor discussed these measures with the operators and it was confirmed that these changes were feasible and practical.

With respect to the acid fume problems, the team evaluated fume exhaust systems. It was determined that an acid fibre filter which collects the acid mist and returns it to the pickle tank while releasing water vapour to the atmosphere would be a major improvement over the existing wet scrubber system which produced large volumes of contaminated wastewater.

The team had used information obtained in the waste reduction audit to determine modifications which would eliminate two sources of contaminated water, reduce acid fume emissions and recover sulphuric acid for reuse in pickling tanks. Having found efficient ways to address the rinsewater and acid fume waste problems, the waste reduction audit team moved on to Step 15.

Step 15: Targeting problem wastes

Step 14 listed the major wastes identified from the waste audit. The "problem" waste streams are the spent pickle liquor and pickle liquor sludge. Due to its corrosive nature, the spent pickle liquor was classified as a hazardous waste under Regulation 347 and therefore its disposal options were limited. The waste pickle liquor sludge is ferrous sulphate monohydrate—a potentially useful chemical with coagulant properties and with potential value for phosphorous removal applications at wastewater treatment plants.

As a result of the audit, a much better understanding of the waste composition was obtained. The team learned that acid loss due to disposal was much higher than first thought. Acid recovery had been discussed in the past by the company, but the characterizations of the waste streams and the material balance calculations of the audit gave the team the reliable data required to justify the purchase of an acid recovery unit as an economically attractive investment.

The characterization results and available options are sh

Table 6: Waste Characterization

Waste	*Analysis*	*Annual Quantity*	*Present Method of Disposal*	*Available Waste Reduction/Treatment Technologies*
Pickle liquor	10% H_2SO_4 7% Fe	2,191 t/a	Off-site	1. Acid Recovery 2. Neutralization
Pickle liquor sludge	40% $FeSO_4H_2O$ 10% FeO (50% solids by weight)	100 t/a	Off-site	1. Off-site Reuse

Step 16: Developing long-term waste reduction alternatives

The team decided that three long term waste reduction/treatment options were available to the company. These were:

Acid Recovery (Option A)
In the acid recovery process, the spent pickle liquor would be pumped to a crystallizer where the iron salts would be crystallized from the spent pickle liquor by cooling. The remaining acid solution would be separated and brought up to pickling strength with the addition of fresh acid. The net effect of the acid recovery system would be to recover the sulphuric acid for reuse, instead of discharging it as waste. In addition, ferrous sulphate crystals would be generated and could be sold as a by-product.

The acid recovery system could be effectively combined with the waste reduction measures described in Step 14, such as a) balancing water into and water out of the pickling tank through the installation of indirect heating, air agitation and counter-current rinsing systems and b) installing an improved fume exhaust system with acid recovery. The combination would avoid any need for treatment or off-site disposal.

Neutralization (Option B)
In this option, a large neutralization system would be installed. The spent pickle liquor and rinsewaters would be combined and neutralized with lime. This process would produce a calcium sulphate/iron hydroxide sludge which would require subsequent dewatering and disposal.

Current Method
This option entailed renewing contracts with haulage companies which find the most economical means for disposing of the hazardous spent pickle liquor. In Autonut's case, the haulage company had been transporting the spent pickle liquor to an oil recovery facility. Autonut had to pay for haulage and disposal fees.

Although no major investment costs would be incurred with this option, the Autonut management was hoping to become less dependent on off-s

disposal due to the high disposal costs. However, if Autonut selected this option it would still have to upgrade its existing wastewater treatment facility and deal with its air emissions.

Before any of the above three options could be implemented the waste reduction team would need to justify the action plan to management. The waste audit team decide to develop cost/benefit analyses for the three options.

Phase Six: Cost/Benefit Analysis and Implementing the Action Plan

Step 17: Cost/benefit analysis of waste treatment/waste reduction

The team proceeded to compare the economics of the acid recovery system, the neutralization system and the existing contract hauling option. From discussions with suppliers of acid recovery systems, the engineer determined the capital and operating costs of an acid recovery system. In addition, capital and operating costs for a neutralization system were obtained from appropriate suppliers. The results of the cost/benefit analyses are shown in Table 7.

Table 7: Comparison of economics for treatment/reduction options at Autonut Ltd.

(All costs in thousands of dollars)

Item	*Basis*	*Current Method*	*Acid Recovery Option A*	*Neutralization Option B*
Capital Investment	25,000 t/a pickling plant	0	800	1,200
Labour				
Operators	$25,000/man-year	12.5	25.0	25.0
Foreman	$30,000/man-year	0	3.0	7.5
Utilities				
Steam	$11/1000 kg	17.6	17.6	17.6
Water	$0.35/m^3	10.5	1.2	10.5
Electricity	$0.04/kWh	2.5	10.5	6.5
Raw Materials				
H_2SO_4 (93%)	$110/tonne	67.5	36.0	67.5
Waste Disposal				
Pickle Liquor	$165/tonne	361.0	0	0
Pickle Liquor Sludge	$177/tonne	17.7	0	0
Neutralization Sludge	$40/tonne	0	0	59.0
Wastewater Costs				
Caustic	$450/tonne	23.9	0	0
Lime	$75/tonne	0	0	36.1
Sewer Fees	$0.35/m^3	9.4	0	9.4
Maintenance	6% investment	0	48.0	72.0
By-Product Credit[2]	$FeSO_4 \cdot 7H_2O$ crystals	0	(9.1)	0
Total Annual Cost		521.9	132.2	311.1

[illegible] Cost Saving for Acid Recovery System	=	$521,900 - $132,200	=	$389,700
Payback Time	=	CAPITAL COST / SAVINGS		
	=	$800,000 / $389,700	=	2.0 years
Total Annual Cost Saving for Neutralization System=		$521,900 - $311,100	=	$210,800
Payback Time	=	$1,200,000 / $210,800	=	5.7 years

Note 1: The engineer's calculations did not consider interest on investment, as he initially wanted to determine a straight-line payback period. Of course interest on investment must be taken into account when detailed return on investment calculations are made. Other items like depreciation allowance, additional costs for upgrading the current wastewater treatment system (if contract hauling is maintained) and the escalating costs of waste disposal must be factored in.

Note 2: Autonut was responsible for hauling the ferrous sulphate crystals ($FeSO_4 \cdot 7H_2O$) to a chemical company ($17/tonne) and received payment for the crystals in return ($27/tonne).

These calculations show a savings of $389,700 per year in operating costs which means that the acid recovery unit would pay for itself in about two years if interest on investment is not taken into account.

Step 18: Implement the action plan: reducing wastes and improving production efficiency.

The engineer presented these cost/benefit analyses to the waste reduction audit team. The team formulated recommendations to purchase and install an acid recovery system, balancing water into and out of the pickling tank, installation of indirect heating, air agitation, counter-current rinsing systems, and installing an improved fume scrubber with acid recovery (as described in Step 14). Chemical companies were also contacted and lined up to market the ferrous sulphate by-product.

The waste reduction team prepared a report which outlined the recommendations, an action plan, the costs involved, the benefits, both economic and environmental, and a schedule for implementation.

The results of the waste audit, the cost/benefit analyses and the recommended action plan were presented to a specially convened meeting of Autonut management. Management was quickly convinced that they had been wasting valuable resources for years, and they agreed that by install-

Table 1: Major Plant Processes and Brief Functional Description

Unit Process	*Brief Functional Description*	*File No.*
Alkylphenol synthesis	Alkylation of phenol for external sales and as intermediate for production of wetting agents	1
Non-ionic detergent synthesis	Ethoxylation of alkylphenol to make industrial wetting agents	2
Amide synthesis	Reaction of fatty acids and fatty amines with ethanolamines to make amide type foam stabilizers	3
Sulphonated anionic detergent synthesis	Sulphonation of alkylated benzenes to make linear alkyl benzene sulphonates (LAS)	4
Cationic detergent synthesis	Reaction of tertiary amines with methyl chloride to produce a quaternary ammonium chloride (for fabric softening)	5
Detergent formulation	Blending of tertiary chemicals to produce final detergent products	6

Step 2: Constructing a process flow diagram

A schematic flow diagram was then prepared to show the inter-relationship of the process (Figure 1).

Once all the unit processes were identified and described, the plant chemist proceeded to assemble information on raw materials, handling losses, water usage and waste reuse as shown in the following Steps 3 to 6.

Because of the complexity of Sud Chemical's processes and the large number of unit processes involved, only the alkylphenol production process will be described in detail in the waste audit section (Phases 1 to 4) of this case study. The waste reduction strategy is then discussed for the whole plant in Phases 4 and 5.

Phase Two: Defining process inputs

Step 3: Determining annual raw material usage

The plant chemist then began sifting through the company's accounting and purchasing records to determine the precise quantities of utilities, chemicals and supplies purchased. This aspect of the work also became a good check on measurements taken in the plant. The following information (Table 2) on raw material usage was obtained for the alkylphenol production process.

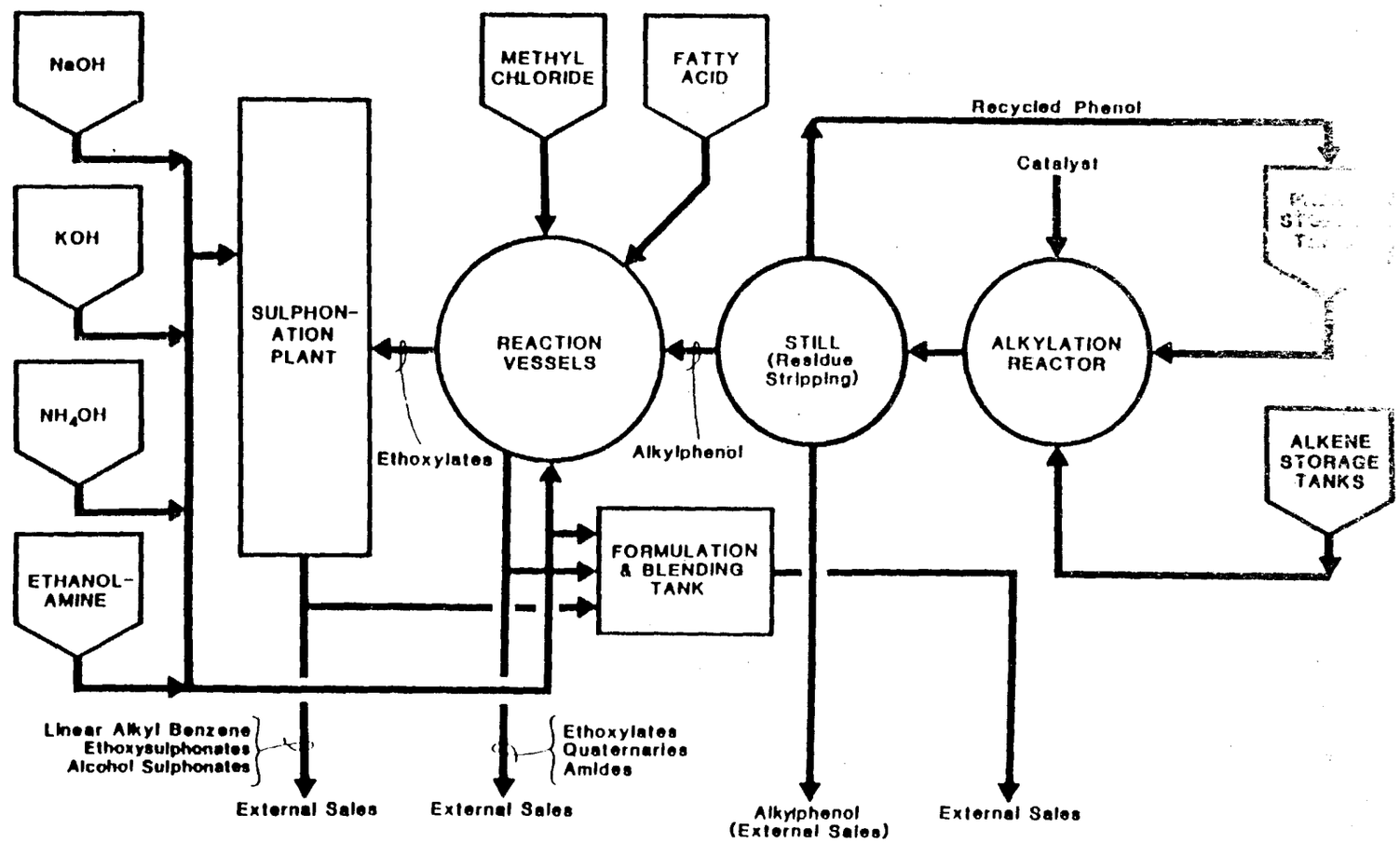


Figure 1: Schematic flow diagram of Sad Chemical's process

Table 2: Raw Material Usage

	Annual Raw Material Usage (tonnes)		
Unit Process	*Alkenes*	*Phenol*	*Catalyst*
Alkene storage tank	1400	-	-
Phenol storage tank	-	1000	-
Alkylation reaction vessel	1400	1000	2.4
Distillation	-	-	-

He was unable to obtain information on water usage from the purchasing records as all the water used for the cleaning and cooling processes was obtained directly from the lake. He determined the water usage through field measurements described in Step 5.

Step 4: Investigating raw material storage and handling losses

Due to the large number of raw materials used at Sud Chemical the plant chemist spent a long time accounting for the raw material storage and handling practices at the plant. His thoroughness was rewarded, though, and he was able to identify a number of losses which occurred through the plant. He noted down his observations and the reasons why losses were occurring.

In the alkylphenol production process, for example, he found that a significant quantity of phenol was lost as a vapour from the phenol storage tank vent and immediately recommended that a condenser system be installed.

Step 5: Recording water usage

The next step was to account for the water usage at the plant and determine what happened to the water. The plant chemist had no idea of how much water was being used in alkylphenol production and therefore decided to quantify its use. The washing frequency was directly related to changeover from one product to another. The plant chemist accurately recorded the product type and water usage over a two month period.

He determined that the still was washed out approximately once every week and that 7000 litres of water were used per clean out. He extrapolated this result to determine the annual water usage. The alkylation reaction vessel was washed infrequently and after speaking to his foreman he found out that it was cleaned out every six months with 8000 litres of water. He confirmed this by measurements in the plant.

The water consumption for the alkylphenol production process is shown in Table 3.

Table 3: Water usage in alkylphenol

Water Use	Quantity of Water Used Per Annum (m^3)	Quantity of Wastewater Discharged to Treatment Per Annum (m^3)
Alkylation Reaction Vessel Cleaning	16	16
Still Cleaning	350	350
Alkylation Reaction Cooling	2700	-
Still Condenser Cooling	2300	-

All the water used at the plant was obtained directly from the lake. Although no accurate consumption figures were available, the plant chemist estimated that a total of 1700 m^3 of water were used at the plant each day. He based his estimate on pumping records, pump data and a pumping test. Most of the water was returned directly to the lake although 250 m^3 per day of contaminated water was passed for treatment in the aeration basin.

While accounting for water usages the plant chemist realized that the vast majority of the wastewater was generated from the washing and cleaning processes and he made a note that this was an area for waste reduction.

Step 6: Measuring current levels of waste reuse

Some wastes were reused at the plant. In the alkylphenol production process unreacted phenol was stripped from the residue, in a distillation stage, for reuse back to the phenol storage tank. The plant chemist took measurements and estimated that 500 tonnes of phenol per annum were reused.

Phase Three: Defining process outputs

Step 7: Listing process outputs

The plant chemist listed the process outputs from the alkylphenol production process as below (Table 4).

ing the acid recovery system they would save on raw materials as well as eliminate waste and pollution problems. Furthermore, the pickling efficiency was expected to be improved by some 25 percent through better control of the pickling bath acid concentration and the improved agitation which would accommodate the company's plan to increase production.

Motivated by environmental and economic pressures, Autonut personnel came to realize that production efficiency, waste management and pollution concerns were interrelated. Through hard work and a deliberate waste audit/waste reduction approach, and by implementing their action plan, they succeeded in:

- improving process efficiency
- saving on raw materials
- eliminating waste and disposal problems
- improving relations with regulatory authorities and local residents.

Because of the benefits gained through conducting a waste audit on the pickling process, the company proceeded to conduct a similar study in the manufacturing plant.

Case study 3: [illegible]

Sud Chemical is a detergent manufacturing facility in a popular resort area of Ontario. It produces a large number of intermediate and final detergent based products which are generally manufactured by batch processing in response to customer demand. The plant's processes, therefore, involve frequent changeovers from one product to another which result in significant quantities of wastewater being generated from process equipment cleaning operations.

Overall, the plant produces a relatively high volume, concentrated and complex wastewater which used to be discharged directly to a small lake popular for recreational activities. However, in response to complaints from cottage owners and pressure from the Ministry of Environment and Energy (MOEE), Sud Chemical installed a concrete aeration basin to pretreat the wastewater before discharge to the lake. Unfortunately, the aeration basin did not perform up to expectations and very low organic removals were achieved, particularly in the winter months. Consequently the MOEE issued a final control order on Sud Chemical, giving it a limited period of time to clean up the wastewater or face plant closure.

Sud Chemical was unsure how to approach its problem. Various alternatives had been proposed by different companies to improve the wastewater treatment system but Sud Chemical was not convinced these systems were adequate and the projected costs were considered to be far too high. Having established that the "end-of-pipe" wastewater treatment option was prohibitively expensive, Sud Chemical management decided to move back up the pipe and see if waste reduction at source could be implemented. The plant chemist contacted OWMC for advice.

Since the plant chemist was the person most familiar with all the chemical processing operations and the water usage at the plant, he was designated as the waste audit supervisor. The following case study describes the waste audit/waste reduction approach taken.

Phase One: Defining process inputs

Step 1: Listing of unit processes

The plant chemist started off his waste audit by identifying the major unit processes at his plant and then proceeded to accumulate as much information as he could about them. He found that he was collecting so much information that he opened a file for each process. The processes were listed as in Table 1.

Table 4: Process outputs

Unit Process	*Product*	*Waste Reused*	*Airborne Waste*	*Liquid Waste*	*Solid Waste*
Phenol Storage Tank	–	–	Vapour loss through vent	–	–
Alkylation Reaction	Alkylphenol/ plant & excess phenol (2900 tonnes)	–	–	washwater	spent catalyst
Distillation	Alkylphenol (2400 tonnes)	Phenol (500 tonnes)	–	washwater still bottom	–

He then proceeded to quantify these outputs in Steps 8 to 10.

Step 8: Accounting for wastewater flows

The plant chemist had determined the annual water usage in the alkylphenol production process in Step 5 and was therefore able to complete Table 5 as follows:

Table 5: Wastewater flows

	Discharge to		
	Treatment Plant		*Lake*
Source	*Flow (m^3/annum)*	*Concentration BOD (mg/L)*	*Flow m^3/annum*
Reaction Vessel Cleaning	366	2100	–
Cooling	–	–	5000

All plant wastewaters from the process equipment washing operations were collected in a common subsurface drainage system and passed to the aeration basin before discharge to the lake. The plant chemist sketched out the drainage system and identified the major wastewater points of entry. He was concerned that no capacity existed to divert or hold any spills or leaks and noted this in his records. The plant chemist estimated the wastewater flow to the aeration basin to be 74,000 m^3 per annum. He estimated that 450,000 m^3 of cooling water and uncontaminated process wastes were returned directly to the lake each year.

Step 9: Documenting wastes stored and hauled off-site for disposal

According to the company's waste disposal records, 3000 kg of spent catalyst and 8000 kg of still bottoms were hauled off-site each year. The spent catalyst and still bottoms are both regarded as hazardous wastes under Regulation 347 of the Environmental Protection Act.

Phase Four: Material balance study

Step 10: Listing of process input and output information

The plant chemist then began listing all the input and output information (Table 6) in order to conduct a material balance and to determine if there were any obvious information gaps.

Table 6: Process inputs and outputs

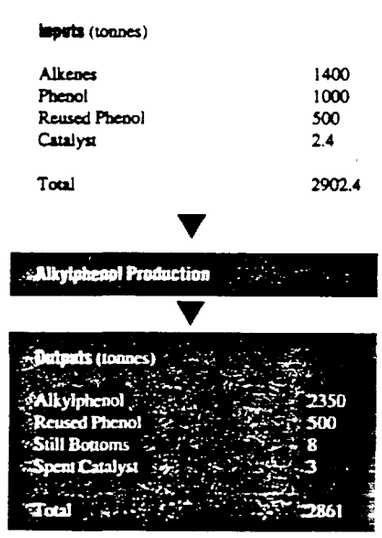
Alkylphenol Production Process

Inputs	Annual Quantity (tonnes)
Alkenes	1400
Phenol	1000
Reused Phenol	500
Catalyst	2.4
Cooling Water	9000
Wash Water	366
Outputs	**Annual Quantity (tonnes)**
Alkylphenol	2350
Reused Phenol	500
Still Bottoms	500
Spent Catalyst	3
Cooling Wastewater	9000
Wash Wastewater	366

Step 11: Deriving a preliminary material balance

A preliminary material balance was then constructed for the alkylphenol production process as in Figure 2. Cooling water and wash water were not considered in the mass balance as these inputs were assumed to equal the wastewater outputs. However, the quantities of organic material which were discharged in the wastewaters were subsequently estimated from measurements of chemical oxygen demand.

Figure 2: Preliminary material balance



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Step 12: Evaluation of the material imbalance

The plant chemist was confident that he had an adequate material balance for the alkylphenol production process. Furthermore, he estimated from the wastewater analyses that approximately 70 kg per annum of alkyl phenol was lost in the wastewater.

Step 13: Refining the material balance

The plant chemist developed the waste audit and material balances for all his unit processes. When he had finished he felt much more knowledgeable about his plant, its inputs, outputs, wastes and problems. By making critical observations and taking notes while he was conducting the waste audit he had also identified a number of waste reduction opportunities.

Phase Five: Waste reduction alternatives

Step 14: Obvious waste reduction measures

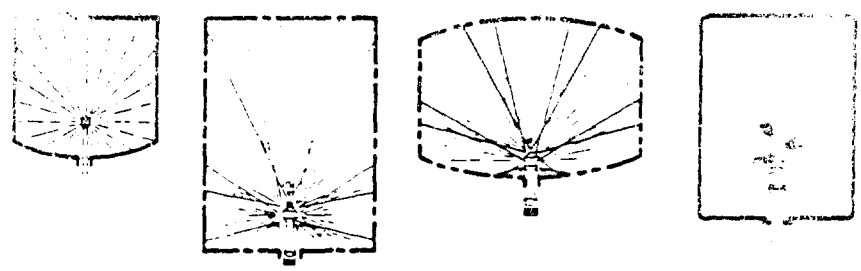
During his audit, the plant chemist had measured wastewater flows and had also taken numerous samples for analyses. This information not only helped to refine his material balance but also helped to identify the major sources of pollution. The information he collected indicated that process equipment washwaters were by far the biggest source of wastewater and product loss in all the processing areas. Furthermore, he considered that the washout procedures, which he had taken for granted for years, were extremely wasteful.

The washout procedures involved filling the reaction vessels with water, cleaning with detergent, and then rinsing. The plant chemist decided to conduct some washout tests at the plant laboratory. He performed these tests with the object of producing a low volume concentrated washwater for potential reuse and for minimizing the total washwater volume. He found that by diverting the initial high concentration washwater to a holding tank he could prevent the bulk of the contaminants from entering the wastewater. Furthermore, product formulation tests indicated that product quality was not impaired when high concentration wastewater was blended back into production.

This was just the start of a concerted effort to reduce the volume and concentration of the wastewater requiring treatment. The following procedures were also implemented:

- Ball washers were installed to increase the efficiency of vessel washouts. Ball washers are spraying devices which give a powerful and thorough wetting of tank and vessel walls to provide effective

[illegible]outs. A variety of ball washer systems are available [illegible] and shapes of vessels (see below).



- Improved product scheduling was initiated to minimize changeovers and corresponding required cleanouts. For example, the product formulation tank cleanout frequency was reduced from five to two times per week through better scheduling. Larger storage tanks were also installed to increase the length of production campaigns, further decreasing the number of cleanouts required. The plant chemist also started to dedicate tanks to specific products.

- Special washwater tanks were set up to hold wastewaters for subsequent use in detergent formulation.

- Tanks were either bought or modified to facilitate easy and efficient washout and drainage, (i.e. tanks were made to pitch, had rounded bottoms, were elevated from the floor and sloped to the exit valve).

- Simple leaks and dripping valves were repaired, packing glands on pumps were replaced by mechanical seals wherever possible and a new maintenance programme was initiated to keep equipment in good repair.

- Level controls and, in some cases, larger tanks were installed to prevent overflows.

- Monitoring of specific wastewaters was stepped up with the installation of good quality flow measuring equipment and increased sampling and analysis.

- Modifications were made to the wastewater drainage system to enable spills and leaks to be diverted and stored if necessary. In this way shock loadings of contaminants were prevented from disrupting the treatment system and causing environmental pollution.

- Probably as important as the practical waste reduction measures was the change in attitude of all employees towards the generation of waste, prevention of spills and water use. An education program was organized by the plant chemist which helped to make all employees more waste prevention conscious.

Everyone attended a series of talks entitled "Washing profits down the drain" which used photographic slides to show wasteful and poor processing techniques and improved practices resulting in waste prevention. An employee suggestion program gave financial bonuses for ideas which resulted in improved efficiency and waste reduction.

As a result of these efforts, the wastewater volume from the treatment facility was reduced by 40 percent (from 250 m^3/day to 150 m^3/day) and the total contaminant loading of the plant's wastewater (as measured by the chemical oxygen demand) was reduced by 50 percent.

Step 15: Targeting problem waste streams

The management at Sud Chemical was very pleased with the results of the waste reduction program. However, the MOEE, although equally impressed with the improvements made, were still unhappy about the contaminant loadings being discharged into the lake. The MOEE maintained that its control order stipulation for discharge of 15 mg/L biochemical oxygen demand, 15 mg/L suspended solids and 0.5 mg/L total phosphorus must be met. Having reduced their waste output considerably, the Sud Chemical management targeted their efforts to treating the reduced total plant wastewater stream.

The plant chemist decided to characterize his total plant wastewater and conducted an extended sampling programme. The average results are shown in Table 7.

Table 7: Characteristics of total plant wastewater

Parameter	*Average Wastewater Concentration (mg/L)*
Flow (m^3/d)	150 (m^3/d)
BOD	2400
pH	9 (pH units)
Suspended Solids	150
Total Phosphorus	3
Phenol	50

The high BOD (biochemical oxygen demand) indicated that a biological treatment process was required. But the presence of poorly biodegradable materials was of concern. The plant chemist proceeded to investigate wastewater treatment options in Step 16.

Step 16: Developing long-term waste reduction alternatives

The plant chemist decided to recommend that Sud Chemical employ a consulting engineering company in order to determine the best alternatives for the wastewater treatment system. He was satisfied that he had implemented good sound measures based on his waste audit to significantly

[illegible], but now realized that the upgrading of the wastewater [illegible]ent facility required specific expertise and engineering skills. The [illegible]gement of Sud Chemical agreed with the plant chemist's recommen[illegible]tion and an engineering company was retained to upgrade the treatment facility.

The upgraded system involved converting the existing aeration basin to an activated sludge treatment system with a secondary clarifier and associated sludge return pumping and pipework. Design points of particular interest included a floating cover and steam injection for temperature control during winter operation, addition of readily degradable substrate (methanol) to assist overall biodegradation (obtained by storing plant wastewaters) and addition of alum to assist secondary clarification and phosphorus removal.

Phase Six: Cost benefit analysis

Step 17: Waste treatment cost benefit analysis

Sud Chemical was placed in a position of having to upgrade its wastewater treatment system in order to comply with a control order from the MOEE. However, the cost of the upgrade system, based on the existing wastewater flow, was prohibitively expensive (approximately $1 million). In Sud Chemical's case, significantly reducing waste was the only practical waste management approach to take. By moving back up the pipe and conducting a waste audit on its processes, Sud Chemical was able to identify, segregate, and, in some cases, reuse its waste washwaters to achieve significant waste reduction.

The total cost of implementing the waste reduction measures described in Step 14 was approximately $50,000. Sud Chemical estimated that the savings made in reducing raw material use amounted to $20,000 per annum. This represents a straight line payback of investment of 2.5 years. More important, however, the waste reduction program significantly reduced the wastewater flow rate so that the existing aeration basin could be modified to an activated sludge system and the associated clarifier and equipment could be sized at approximately half the level required at the old flowrate. In this respect the total cost for the wastewater treatment plant upgrading of $500,000 represented a very significant saving compared to earlier cost estimates.

The waste audit approach, and subsequent waste reduction, almost certainly saved Sud Chemical from closing down. The plant is now thriving and production has increased by 25 percent. Not only has Sud Chemical managed to reduce water usage, raw material usage and waste loads but it also improved public relations and profits as well.

Pollution Prevention and Chemical Engineering

NATIONAL POLLUTION PREVENTION CENTER FOR HIGHER EDUCATION

Open-Ended Problem: Determining Mass Balances in Ford-Wixom's Phosphate Coating System

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Produced in cooperation with:

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Environmental Quality Office. Ford Motor Company,
Susan Montgomery, assistant professor
Department of Chemical Engineering University of Michigan

Accompanying multimedia tour by Michael Africa.

Note to instructors: If your students have access to a microcomputer with a CD-ROM drive, consider acquiring the multi-media tour of the Ford-Wixom Phosphate Coating System that accompanies this open-ended problem. The tour includes video clips of the actual system, a short description of each of the system's 12 stages, and supplementary explanations.

The CD-ROM is available from the NPPC for $20. It runs on both Macintosh and Windows systems. For the Macintosh, you'll need a Mac II or better — a 68020 chip is the minimum; for tolerable playback, use a machine with a 68030 or higher chip, such as an LCIII, SE/30, or better. It also requires at least 8MB RAM and System 7.0.1 and QuickTime 1.5 or higher (QT does not work well with System 7.0). The IBM-PC Microsoft Windows system requirements are: a 386 machine or higher with 8MB RAM, DOS 6.0 or later, Windows 3.0 or later, QuickTime for Windows 1.1.1 or later (currently at version 2.0), and screen resolution of 640*480 or higher.

Your Assignment

Part 1

You were just hired as a junior engineer at Ford Motor Company. On the fifth day your boss gives you your first "real" assignment (the first four days you always spend reading). She says that the phosphate system is costing more than expected. She gives you a bit of reading material on the system (surprise, surprise) along with some data from last year and the name of the supervisor in charge of that system. She says that chemical usages are known and the controller's office has the costs for them. However, any type of water usages are not known. Sounds simple enough. You call the supervisor of the phosphate system and ask him to show you around (the plant floor is more than two miles long, so not all the systems are easily found). As you walk through the system looking for the flow meters on the water pipes, you notice there aren't any. Hmm . . . this could be a problem. You thank the supervisor and head back to your office (a 3' x 6' cubicle—a lot like a restroom, but with lower walls).

A couple hours later, while you are poring through the phosphate system material, the senior engineer, who has a cubicle around the corner, stops by to see how you are doing. You explain the assignment you have been given. After noticing the blank page in front of you, he offers a bit of advice: "You should make a table something like this."

Stage	Function	Chemicals/Streams In	Out

"Could you fill this in?" he asks. He adds that it's always a good idea to create a flowsheet and mass balance of the system to get a good understanding of what is going on. You nod and thank him, knowing that you can count on him if you run into trouble again. After looking through the material, you begin filling in the chart.

Stage	Function	Chemicals/Streams In	Out
Pre-Wash	Initial cleaning	Preclean X Water	Carry-out on cars

Part 2

Your supervisor has just poked her head into your cubicle and returned your flowsheet along with your report containing the mass balances and water usages on the phosphate system. She stresses that the most important thing is not the comments made on your work, but that now your feet are wet and and you have a good overall understanding of what goes on at the phosphate system.

Now she says she has a real challenge for you (sweat and worry emerge). She gives you more reading material (surprise, surprise): a Ford document called "Roadmap to an Effective Waste Minimization Program." She tells you to team up with 2–3 other junior engineers on staff and target the phosphate system for waste minimization. In particular, she would like some alternatives to the chromium rinse in an effort to find something more environmentally friendly.

On her way out, she tells you to get familiar with the waste minimization program, asks you to have a recommendation, including post-treatment alternatives, on her desk in two weeks, and bids you good luck!

The Phosphate Coating System

In building quality products that require painting, excellent appearance and corrosion resistance are extremely important customer expectations. Paint, however, does not readily adhere to a pure metal surface, such as cold rolled steel or aluminum. Before metal can be painted, a surface coating (also known as a conversion coating) is applied that will retard base metal corrosion and allow the paint to firmly adhere to the metal.

A chemical conversion coating process, typically using a phosphate material, is applied to the metal prior to painting. This process transforms a metallic surface to a non-metallic or semi-metallic crystalline surface. Once the metal undergoes the phosphate coating, the resulting inorganic crystalline coated surface provides an excellent base for paint.

The purpose of the phosphate coating as a base for paint is to:

- improve paint adhesion
- reduce metal-to-paint reactions
- improve corrosion resistance[1]

Because of the improved durability of the final product, phosphate coatings are used to prepare most painted metal objects produced by industry today. The typical, high-quality pre-paint conversion coating process consists of the following steps:

- Clean metal surface
- Rinse
- Apply phosphate coating
- Rinse
- Conduct post-phosphate treatment
- Rinse with deionized water

This process varies throughout industry, depending on end-product quality performance criteria and the base metal being coated (e.g., steel, aluminum).

The phosphate coating system was installed at Ford Motor Company's Wixom Assembly Plant in 1989. During the summer of 1993, a study of the system was performed. Based on this system, the following is a description of an industrial phosphate conversion coating process.

Metal Surface Cleaning

Vehicle bodies/panels (parts) enter the phosphate coating system after being stamped into their respective shapes and, in many instances, welded together. During the stamping and welding process, many oils and other compounds are used, and dirt and weld residue contaminate the parts. For high-quality conversion coating of the phosphate material, each part's surface must be thoroughly cleaned. The bulk of the unwanted deposits are removed by sending the parts through a high pressure spray "pre-wash" system. The pre-wash consists of a 450-gallon tank of ambient-temperature water containing 30–40% preclean material ("Preclean X").

This separate pre-wash system removes the loose dirt and oils and minimizes contamination. However, a more thorough cleansing is still required. It is imperative that all oils and dirt be removed from the parts to ensure adequate coating, good corrosion resistance, and a high quality painted metal surface: any soil present on the surface will result in a non-uniform coating. For this reason, the first two stages of the phosphate coating system have the function of cleaning parts. The cleaning takes place in two stages to be certain that all surfaces come in contact with the fluid.

Stage 1 involves high-pressure spray cleaning at a temperature between 120 and 130°F. The most common cleaner used by the metal-finishing industry today is alkaline (hydroxides, phosphates, carbonates, silicates, etc.), which reacts chemically with the dirt and oils to remove them from the surface. Alkaline components also suspend the particles in solution so that they do not redeposit onto the metal surface. There are two chemical products, "Cleaner A" and "Cleaner B," along with soft water which collect in the 7,000-gallon tank. A tank overflow pipe discharges into the floor drain at a rate of 1.5 gallons per minute (gpm) to the plant's wastewater treatment facility.

Stage 2 uses a 56,500-gallon immersion tank to dip-clean the parts. The same cleaning chemicals, along with soft water, are fed to this stage as were fed to Stage 1, but with a different method of application. The immersion application alleviates any concerns with part complexity: once immersed in the bath, the part has been cleaned on the inside *and* the outside. Stage 2 was designed to overflow into Stage 1 to reduce raw material usage.

Rinse

Once cleaned, the parts must be rinsed thoroughly to remove any cleaning chemicals and prevent contamination of other baths. Stages 3 and 4 are ambient temperature water rinses, with Stage 4 overflowing into Stage 3. **Stage 3** is a spray-water rinse. A 3,000-gallon tank is at ambient temperature and has two overflow pipes. One overflow pipe dispenses rinse water to the floor drain at a rate of 8.4 gpm; the other overflows to the process line between the pre-wash and Stage 1. **Stage 4** is a second spray rinse of the same size and conditions.

Phosphate Coating

After the parts have been cleaned and rinsed, the surface of the metal needs to be physically prepared to accept the zinc phosphate treatment. The surface chemistry takes place in an immersion rinse conditioning stage (**Stage 5**). In this stage, a surface activating agent reacts with the metal surface to create nucleation sites for the growth of crystals. "Primer A" and "Treat TP," along with soft water, are added to promote the formation of nucleation sites. Primer A is a caustic cleaner; Treat TP contains the activating agent (titanium phosphate). The bath size is 40,500 gallons and is maintained at 120°F. There is an overflow pipe with a flow rate of 1.7 gpm discharged to the wastewater treatment stream.

After the metal surface has been satisfactorily cleaned, rinsed, and conditioned, it is ready for the conversion coating solution. Most conversion coatings used by the metal-finishing industry today are based on mixtures of partially neutralized phosphate acid[1]. The process is governed by the following reactions[1]:

$$Fe\ (filing) + 2H_3PO_4 \rightarrow Fe(H_2PO_4)_2 + H_2$$
$$Fe\ (surface) + Fe(H_2PO_4)_2 \rightarrow 2FeHPO_4\ (insoluble) + H_2$$
$$Fe\ (surface) + 2FeHPO_4 \rightarrow Fe_3(PO_4)_2\ (insoluble) + H_2$$

Stage 6 is a 63,500-gallon immersion phosphate bath. At 110–120°F, the acidic phosphate material reacts with the surface of the metal to form an inorganic, crystalline-coated surface. The titanium phosphate activating agent that has been absorbed physically onto the metal surface exists as small colloidal particles that serve as the nucleation sites for the growth of the crystalline conversion coating. "Bonderite P" (the phosphate material) is the chemical added, along with water, at this stage to apply the conversion coating.

However, barely any hydrogen is released during the reaction, a thin film of hydrogen forms on the surface, causing slow growth of the crystals. To help alleviate this situation, "Accelerator A," a sodium nitrate solution that is an oxidizing agent, is added in Stage 6 to convert hydrogen gas to water. It also oxidizes the iron, which dissolves in the phosphate solution. Iron concentrations must be controlled to minimize the formation of crystalline iron phosphate *and* zinc phosphate, which would result in a darker color and a much higher coating weight[2]. In addition, "Additive 1," a fluoride, is used in this bath to enhance a conversion coating on the aluminum portion of the parts. "Additives A, B, and C" include metal ions, organic acids, or chelating agents, which control the overall characteristics of the crystalline coating; they are added as needed.

A specified measurement of 150–300 mg of coating per square foot of part surface is required to provide a good phosphate coating. A necessary by-product of this process is the formation of sludge. Sludge is produced by the iron, which is dissolved and then oxidized in the solution to form an insoluble mixture of ferric phosphate and ferrous phosphate. The sludge from Stage 6 is allowed to precipitate and then passed through a filter press for dewatering; after that, its density is typically 30–40% solids. The phosphate solution is then returned to the tank while the sludge is removed and eventually disposed of in a landfill. Temperature is a very important control parameter because of the inverse solubility of zinc phosphate with increasing temperature[2]: too high a temperature will result in excessive sludge formation, while too low a temperature will not yield the specified coating weight.

Once the parts leave the phosphate bath, they must be rinsed to remove the unreacted chemicals from the surface in order to prevent or minimize the contamination of the next stage. **Stage 7** is a spray rinse with a 3,000-gallon tank at ambient temperature. It has an overflow pipe to the wastewater treatment sewer and discharge rate of 45 gpm.

Rinse

Following this spray rinse is an immersion rinse. Similar to the setup of Stages 3 and 4, the overflow from **Stage 8**, the immersion rinse, goes into Stage 7 (spray rinse). Stage 8 is also at ambient temperature but has a capacity of 40,500 gallons. This allows for effective rinsing with minimal contamination.

Post-Phosphate Treatment

After the metal surface receives a conversion coating and has been sufficiently rinsed, a post-treatment and final rinse are applied. The function of this post-treatment is to provide approximately a 2- to 10-fold increase in corrosion resistance and humidity resistance[1].

Post-treatment has historically been based on chromic acid, although non-chromate chemicals are in use throughout industry. "Chemical C" and deionized (DI) water provide the chrome rinse for **Stage 9**. Environmental concerns and the water solubility of hexavalent chromium have led to the use of reduced chromates where a percentage of the chromium is Cr^{+3} ions. Thus, pH is a critical parameter at this stage because trivalent chromium precipitates from solution at a pH above 4.8. The pH of this 40,500-gallon tank is kept between 4.0 to 4.5, and the tank is maintained at ambient temperature. To control the pH, two chemicals are added as needed: "Add 1" is a hydroxide solution, which can raise the pH, while "Add 2" is acidic.

One disadvantage of chromic acid is that puddles of the solution cause high concentrations of chromium to form on seams or corners of the parts. This can lead to poor corrosion resistance in these areas. To remedy this situation, excess chrome is rinsed off with deionized water. This ensures that a uniform film of chromic acid remains on the parts, and that no areas of high concentration are present. The deionized (DI) water rinse takes place in three different stages, all at ambient temperature. **Stage 10** is a recirculating DI spray with a tank size of 3,000 gallons and an overflow rate of 25 gpm to the wastewater treatment sewer.

Deionized Water Rinse

Stage 11 is a 40,500-gallon recirculating DI water immersion rinse, which overflows into Stage 10. Both stages receive DI water once a week to provide make-up water for the tanks, which is then recirculated. At the end of Stage 11 is a Virgin DI water spray. All the run-off from the Virgin DI spray flows directly into Stage 11.

Now the parts (vehicle bodies and panels) are ready to be painted.

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[1]Chemfil Corporation, *Phosphate Applications for the Automotive Industry*, Troy, Michigan.

[2]Kent, Dr. Gary D., "Conversion Coating of Metal Prior to Paint," in *Parker Chemical Reference Book*.

[3]Maher, Martin F., and Albert M. Pradel, *Phosphate Coatings*, Oaklite Products, Inc.

Published by:
The National Pollution Prevention Center for Higher Education
University of Michigan, Dana Building
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Ann Arbor, MI 48109-1115
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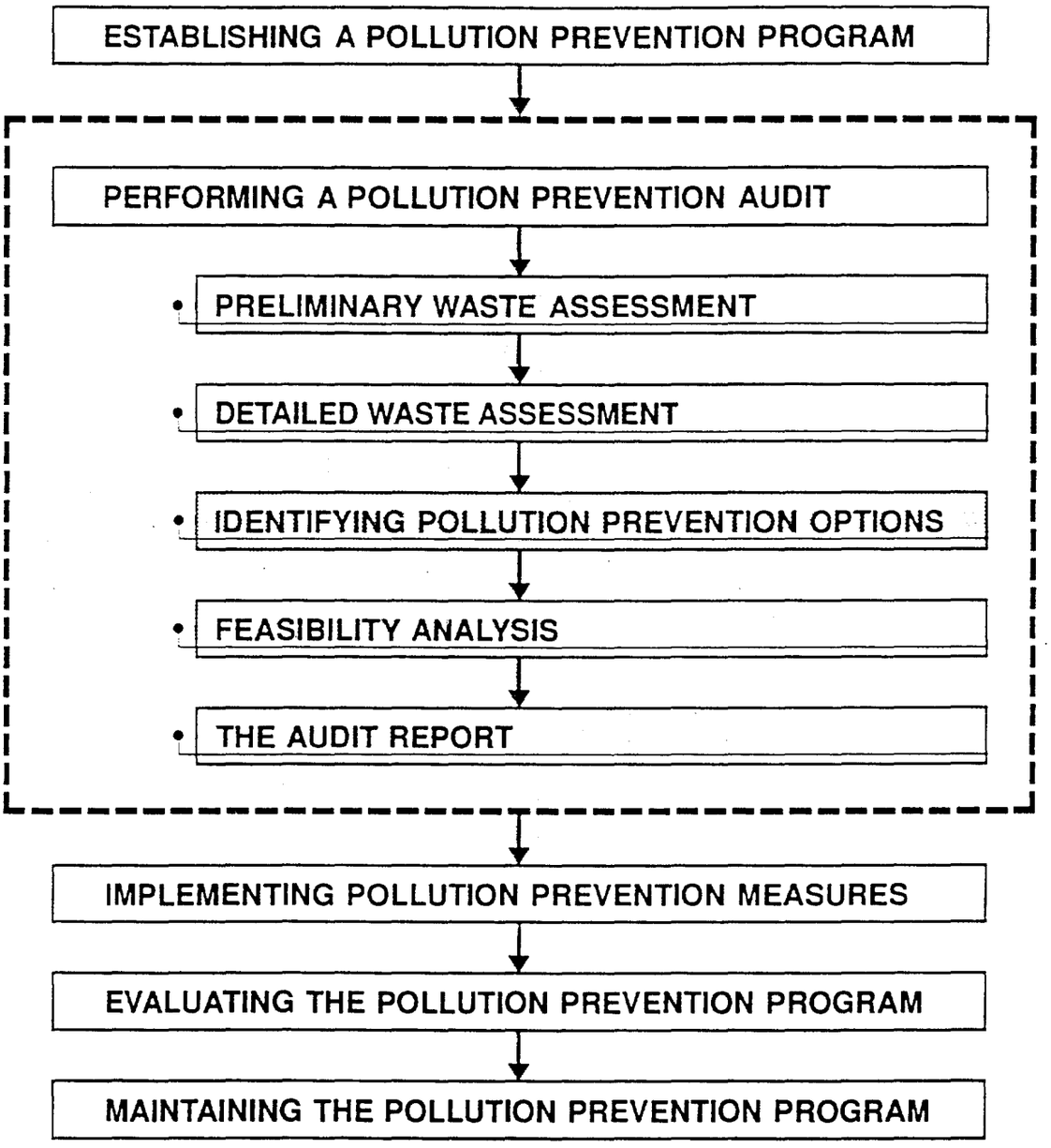
IDENTIFYING POLLUTION PREVENTION OPTIONS

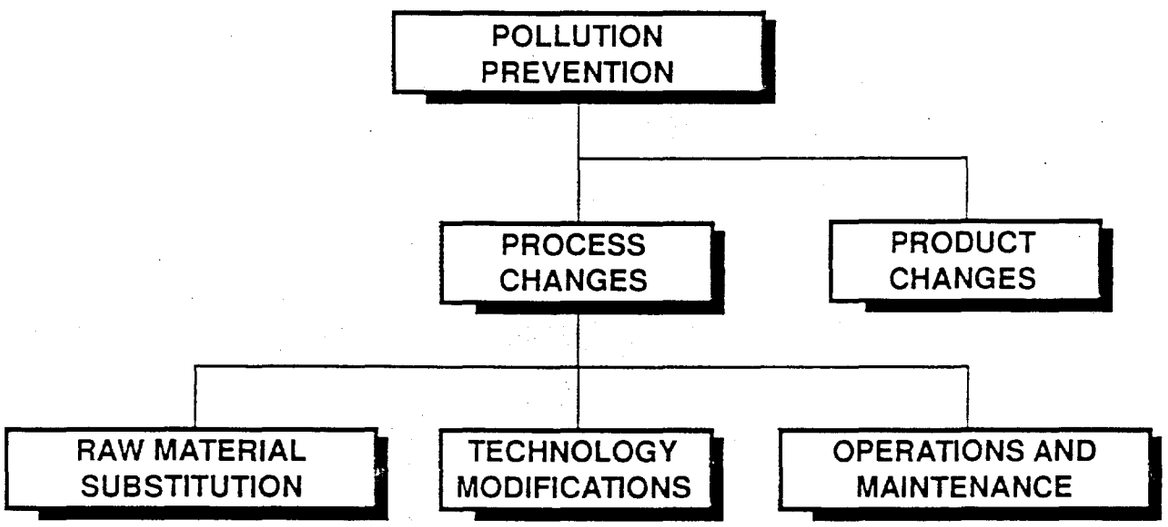

ESTABLISHING A POLLUTION PREVENTION PROGRAM
PERFORMING A POLLUTION PREVENTION AUDIT
• PRELIMINARY WASTE ASSESSMENT
• DETAILED WASTE ASSESSMENT
• IDENTIFYING POLLUTION PREVENTION OPTIONS
• FEASIBILITY ANALYSIS
• THE AUDIT REPORT
IMPLEMENTING POLLUTION PREVENTION MEASURES
EVALUATING THE POLLUTION PREVENTION PROGRAM
MAINTAINING THE POLLUTION PREVENTION PROGRAM

IDENTIFYING POLLUTION PREVENTION OPTIONS

PURPOSE : Based on results from the material balance, generate a list of potential areas for Pollution Prevention to be further studied.

- Process changes
- Product changes

IDENTIFYING POLLUTION PREVENTION OPTIONS



IDENTIFYING POLLUTION PREVENTION OPTIONS

PROCESS CHANGES

- Raw material substitution
- Technology modifications
- Operations and maintenance

IDENTIFYING POLLUTION PREVENTION OPTIONS

RAW MATERIALS SUBSTITUTION

- Solvent substitutions
- Other chemical substitutions

IDENTIFYING POLLUTION PREVENTION OPTIONS

TECHNOLOGY MODIFICATIONS

- Recovery systems
- Rinsing systems
- Cooling operations
- Coating operations
- Separations technologies
- Process control
- Reactor design and chemistry

IDENTIFYING POLLUTION PREVENTION OPTIONS

OPERATIONS AND MAINTENANCE

- Specifying and ordering materials
- Receiving materials
- Material storage
- Material transfer and handling
- Process control
- Cleaning procedures

IDENTIFYING POLLUTION PREVENTION OPTIONS

PRODUCT CHANGES

- Product life extension
- Material selection
- Packaging and distribution
- Labeling

Industrial Pollution Prevention Handbook

Harry M. Freeman

32

Solvent Substitutes

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32.1 Introduction

Petroleum-based solvents have been used liberally as cleaning agents across most industrial sectors in a variety of applications related to fabrication, manufacturing, assembly, and maintenance activities. Historically, industry has selected low-molecular-weight, high-volatility, petroleum-based solvents in order to achieve maximum removal of soils and contaminants, to ensure compatibility with work surfaces and subsequent process requirements, to minimize the need for user technique and process sophistication, and to minimize associated capital and operating costs. The environmental and industrial hygiene regulations promulgated since 1980, most notably the Superfund Amendments and Reauthorization Act (SARA), the Hazardous and Solid Waste Amendments to the Resources Conservation and Recovery Act (RCRA), and the Clean Air Act Amendments of 1990, have brought about an increased emphasis on user exposure, hazardous waste generation, and air emissions. As a result, industry is performing a fundamental reassessment of cleaning solvents, processes, and procedures. The more progressive organizations have made their goal the elimination of solvents that may pose significant potential human health and environmental hazards. The typical hierarchy when one investigates solvent substitution options is to

1. Eliminate the need for cleaning
2. Substitute nonsolvent materials and processes
3. Substitute alternative solvents and processes with reduced hazards and emissions
4. Implement emissions control procedures and technologies

This chapter discusses solvent cleaning in metal-finishing, metal-manufacturing, and industrial maintenance applications; precision cleaning; and electronics manufacturing. Nonmetallic cleaning, adhesives, coatings, inks, and aerosols also will be addressed, but in a more cursory manner.

32.1.1 Solvent History

Halogenated solvents, high-volatility oxygenated solvents, and high-volatility aromatic and aliphatic hydrocarbons have traditionally served as "general purpose cleaners." Table 32-1[1] summarizes the commonly used industrial solvents and their historical processes. Table 32-2[2] lists several fundamental physical and chemical properties of these solvents. Industry dependence on the five halogenated solvents, particularly 1,1,1-trichloroethane (TCA), evolved due to their reduced toxicity relative to their predecessors, their low flammability, their

Table 32-1. Historical Industrial Solvent Use

	Process				
Solvent	Ambient immersion	Heated immersion*	Vapor degreasing	Spray	Manual
Trichloroethylene (TCE)	X	X	X		X
1,1,1-trichloroethane (TCA)	X		X	X	X
Tetrachloroethene (PERC)	X	X	X	X	X
Dichloromethane (METH)	X	X	X	X	X
1,1,2-trichloro-1,2,2-trifluoroethane (CFC-113)		X	X	X	X
Acetone					X
Methyl ethyl ketone (MEK)	X				X
Methyl isobutyl ketone (MIBK)	X				X
Toluene	X				X
Xylenes	X				X
Low-flashpoint aromatic and aliphatic hydrocarbons and blends†	X				X

*Typically in conjunction with vapor degreasing, i.e., immersion in the boiling-liquid sump.
†Includes PD 680 Type I, PD 680 Type II, and Stoddard solvent.
SOURCE: Derived from Ref. 1, p. 203.

Table 32-2. Relevant Properties of Historical Industrial Solvents

Solvent	Chemical formula	Molecular weight	Specific gravity	Boiling point (°C)	Flashpoint (°C)	Surface tension (dyn/cm)*	Kauri butanol value	Vapor pressure (mmHg)†	TLV (ppm)‡
TCE	$CHClCCl_2$	131.4	1.46	86–88	None	29.3	130	65	50
TCA	CH_3CCl_3	133.5	1.34	72–88	None	25.4	124	100	350
PERC	CCl_2CCl_2	165.9	1.62	120–122	None	31.3	91	21	25
METH	CH_2Cl_2	84.9	1.33	39–40	None	26.5	132	358	500
CFC-113	CCl_2FCClF_2	187.38	1.56	47.6	None	17.3	31	304	1000
Acetone	CH_3COCH_3	58.03	0.79	56–57	−17	23.7	—	220	750
MEK	$CH_3COC_2H_5$	72.1	0.80	79–81	−2.2	24.6	—	84	200
MIBK	$CH_3COCH_2CH(CH_3)_2$	100.16	0.82	112–118	17.6	22.7	—	7	50
Toluene	C_6H_5	92.15	0.87	110.6	4.4	28.5	94–105	26	50
Xylenes	$C_6H_4(CH_3)_2$	106.17	0.86–0.88	138–144	26.7	28.4–30.1	94	8	100

*At 20°C.[13]
†At 20°C as interpolated from D-170–D-172, *Handbook of Chemistry and Physics*, 55th ed.[7]
‡OSHA Permissible Exposure Limit, 8-hour time-weighted average, parts per million in air.[3]
SOURCE: Refs. 1, 2, and 9.

superior soil and contaminant dissolution capabilities, their compatibility with work surfaces and process equipment, and their relatively low cost. In contrast, toluene, xylene, methyl ethyl ketone (MEK), acetone, and the low-flash-point aromatic and aliphatic naphthas have been restricted to use as ambient-temperature immersion cleaners and manual-wipe cleaners due to their flammability and potential health hazards. Overall, industry dependence on the solvents identified in Table 32-1 resulted from a rational analysis of the key criteria considered at that time. Clearly, environmental and industrial hygiene considerations are causing a shift in these historical applications.

32.1.2 Regulatory Framework

Table 32-3 identifies the principal environment concerns associated with each of the five halogenated hydrocarbon solvents, MEK, MIBK, acetone, toluene, and the xylenes(s). These concerns are being addressed through the following U.S. environmental laws as well as international agreements.

- Montreal Protocol on Substances That Deplete the Ozone Layer
- Clean Air Act Amendments of 1990
- EPA Industrial Toxics Program (voluntary)
- Superfund Amendment and Reauthorization Act
- Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act

The Copenhagen Adjustments to the Montreal Protocol on Substances That Deplete the Ozone Layer, ratified in October 1992, require that developed

Table 32-3. Historical Industrial Solvent Environmental, Health, and Safety Issues

Solvent	Stratospheric ozone depletion	Ozone depletion potential[a]	Volatile organic compound[b]	Hazardous air pollutant[c]	Historical soil and groundwater contamination	Flammable[d]	Carcinogenicity
TCE	No	0	Yes	Yes	Yes	No	See note[e]
TCA	Yes	0.2	No	Yes	Yes	No	No
PERC	No	0	No	Yes	Yes	No	See note[f]
METH	No	0	No	Yes	No	No	See note[g]
CFC-113	Yes	0.8	No	No	No	No	No
Acetone	No	0	Yes	Yes	No	Yes	No
MEK	No	0	Yes	Yes	Yes	Yes	No
MIBK	No	0	Yes	Yes	No	Yes	No
Toluene	No	0	Yes	Yes	Yes	Yes	No
Xylene(s)	No	0	Yes	Yes	Yes	Yes	No

[a]Ozone depletion potential (CFC-11 = 1.0) as listed in Refs. 1 and 2.
[b]Per Title I of the Clean Air Act Amendments of 1990.
[c]Per Title III of the Clean Air Act Amendments of 1990.
[d]Defined as possessing a flashpoint less than 38°C.
[e]The EPA has not formally classified TCE in Category B2 as a "probable human carcinogen," while the International Agency for Research on Cancer (IARC) has classified this solvent in Group 3, a substance not classifiable as to its carcinogenicity in humans.
[f]The EPA has not formally classified PERC in Category B2 as a "probable human carcinogen," while the IARC has classified this solvent in Group 3, a substance not classifiable as to its carcinogenicity in humans.
[g]The EPA has not formally classified METH in Category B2 as a "probable human carcinogen," while the IARC has classified this solvent in Group 3, a substance not classifiable as to its carcinogenicity in humans.

nations eliminate the manufacture of Class I ozone-depleting compounds (ODCs) by January 1, 1996. The Class I ODC cleaning solvents of concern to use are the following: 1,1,2-trichloro-1,2,2-trifluoroethane, or chlorofluorocarbon 113 (CFC-113); and 1,1,1-trichloroethane (TCA), or methyl chloroform. Figure 32-1[2] shows a breakdown of worldwide TCA consumption. In the United States, Du Pont has announced that they will close their CFC production facilities in developed nations by January 1, 1995.[3] Over 50 electronics manufacturers from Canada, Germany, Japan, Sweden, and the United States halted by May 1993 the use of CFC-113 in global operations.[3] Over 60 multinational companies also completed their global phaseout of CFC-113 in 1993.[3] The rapidly escalating cost of ODC solvents, mainly due to federal excise taxes and their decreased availability, is providing incentive to users of TCA and CFC-113 as bulk cleaning agents to eliminate these compounds as soon as technically feasible.

Title VI of the Clean Air Act Amendments of 1990 also addresses ODCs. Title VI contains a list of all Class I and Class II ODCs. Final rules have been promulgated for Title VI, Section 604 and Section 605, which address phase-out of production of both Class I and Class II ODCs, Section 610 on nonessential uses, and Section 611 on products containing or manufactured with Class I ODC. Section 612 establishes a framework for evaluating potential alternatives. The

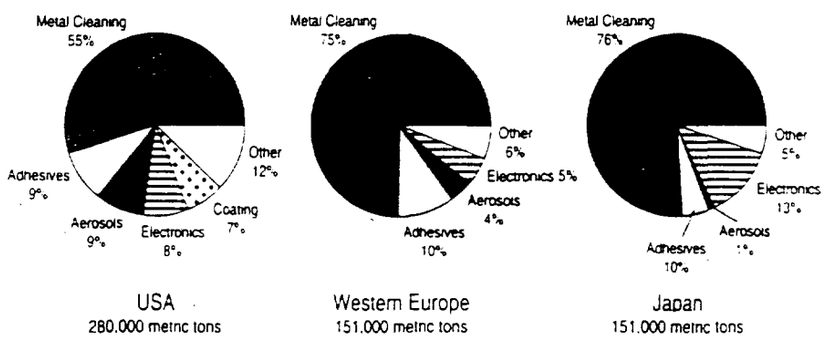

Figure 32-1. Breakdown of worldwide TCA use. (*Courtesy of Chem Systems, 1989.*)

Safe New Alternatives Program (SNAP) of the U.S. Environmental Protection Agency (EPA) will include a list of acceptable substitute categories and a list of chemicals prohibited as substitutes for specific applications. The EPA published the final rule for SNAP in March 1994 in the *Federal Register*.[4] Title III of the CAAA requires regulation of 189 chemicals referred to as *hazardous air pollutants* (HAPs). This list includes all of the solvents discussed above. In addition, Title III will place restrictions on industrial operations located in areas defined as *nonattainment areas* by the EPA. Those solvents defined as *volatile organic compounds* (VOCs) and HAPs (see Table 32-3) are in the process of becoming strictly regulated as to their use and emissions. Industrial users of these solvents will be subject to additional record-keeping and reporting requirements. Significant capital costs may be incurred in cases where these solvents are used in process equipment, due to the need for installation of emission control devices or new process equipment to reduce emissions. The detailed rules for HAPs and VOCs are being promulgated and are anticipated to become effective beginning as early as mid-year 1995. Title III also contains requirements for the prevention of accidental releases of these substances. Industrial facilities will be required to provide a risk management plan for prevention, detection, and response in case of emergency releases.

The EPA Industrial Toxics Program, also called the 33/50 Program, is a voluntary effort to eliminate the emission and off-site transfer of 17 toxic chemicals. The voluntary goal established is a reduction in emissions and transfers of 33 percent by the end of 1992 and of 50 percent by the end of 1995, the 1988 baseline levels. The 17 chemicals include TCA, trichloroethylene (TCE), methylene chloride, perchloroethylene, MEK, methyl isobutyl ketone (MIBK), toluene, and xylenes. Over 1000 major companies had committed to this program as of early 1994.

SARA has required an annual Toxics Release Inventory (TRI) since 1987. The list of off-site chemical transfers and emissions that are to be reported by industrial facilities includes the solvents listed in Table 32-1. In addition, SARA requires contingency and emergency response capabilities for facilities that store and use these chemicals in manufacturing processes.

Lastly, the Hazardous and Solid Waste Amendments to RCRA have placed stringent requirements on disposal of wastes derived from the solvents listed in Table 32-1. These hazardous wastes are restricted from land disposal. Disposal through incineration or as waste-derived fuel-blending stock is increasingly costly and carries potential long-term liabilities for the generator. The chlorinated solvents are the most amenable to recycling. But, under RCRA, recycling of these spent solvents requires management of the spent solvent as hazardous waste and use of the Uniform Hazardous Waste Manifest when these wastes are shipped off-site.

Essentially, the use of any of the solvents listed in Table 32-1 and 32-2 carries a significant environmental regulatory burden that may result in additional capital and operating costs and possible long-term liabilities. Most progressive industries are restricting use of these solvents to those applications in which the use is essential to the product's performance.

The following sections summarize the general technology trends in the elimination of chlorinated and high-volatility petroleum-based solvents use for various applications. The information is organized by industry sector and incorporates information summary tables and a list of observations as to industry trends. A brief list of key references is given at the end of each major section.

32.2 Metal Fabrication and Finishing

In this section, metal-cleaning alternatives are discussed in general terms for this broad industry sector. Relevant categories in the metal-manufacturing industry include automotive, aerospace, rail, ship, appliance, and tooling. Chlorinated-solvent vapor degreasing and ambient-temperature immersion cleaning have been the mainstay of forming-fluid and machining-lubricant removal in metal fabrication and -finishing industries. Wipe cleaning with MEK and high-evaporation-rate solvent blends—e.g., toluene, aromatic naphtha, ethyl acetate, as well as TCA and CFC-113—has been widely used prior to application of coatings to detail parts and during assembly of products. The broad range of metals and alloys and the variety of surface treatments and coatings applied after cleaning make this an industry sector in which alternate materials and processes tend to be numerous and somewhat application-specific.

32.2.1 Summary of Options and Recommendations

Table 32-4[2] summarizes the viable alternative material and process categories for metal cleaning as they pertain to fabrication and finishing. A more detailed summary is given in Table 32-5.[5] Figure 32-2 on page 526 shows the generalized aqueous immersion-cleaning system that is being considered as a replacement for vapor degreasing in most metal-finishing industries. While it is difficult to

Table 32-4. Summary of Metal-Finishing Alternative Materials and Processes

Alternate material	Alternative process				
	Ambient immersion	Heated immersion	Vapor degreasing[a]	High-pressure spray	Manual wipe
Aqueous, alkaline	X	X		X	X[b]
Aqueous, emulsion	X	X		X[c]	X
Low-vapor-pressure solvent blends	X	X[c]		X[c]	X[d]
Aliphatic petroleum hydrocarbons	X[e]				X[d]
Terpene hydrocarbons	X[e]				X[d]
Hydrocarbon-surfactant blends[f]	X[e]				X[d]
Steam				X	
Chlorinated solvents[g]			X		

[a]Specially designed systems which minimize fugitive emissions through enclosed design and vapor recovery devices.
[b]Surfactant-in-water blends under development; requires corrosion-resistant surface and ability to dry.
[c]Appropriate flammability protection required.
[d]Appropriate residue removal technique required.
[e]Includes aliphatic petroleum and terpene hydrocarbons with surfactant chemical additives; these are intended to facilitate rinsing of residues and formation of stable emulsion cleaners when mixed with water.
[f]Includes PCE and TCE, only when used in a specially designed vapor degreaser.

generalize across industrial sectors and for different facilities, the following technical trends would be agreed upon by most scientists and engineers in the metal-manufacturing sector.

A "systems" analysis of the entire manufacturing process frequently reveals opportunities to eliminate redundant or unnecessary cleaning steps and identifies opportunities to reduce the stringency of cleanliness required for a particular operation.

"No clean" technologies are emerging. These technologies will ultimately preclude the need for traditional cleaning methods as they mature; presently they are either not technically feasible or economically unreasonable.

Thermal vacuum de-oiling, solid-film or polymer sheet lubricants, and ultrasonics will emerge as "no clean" alternative metal-forming and -manufacturing techniques.

Aqueous alkaline and emulsion cleaners are dominating the replacement of batch and continuous solvent vapor degreasing and cold cleaning in the United States. Both immersion and spray applications are being employed.

Ultrafiltration can extend aqueous cleaner life.

Hydrocarbons, TCE, and perchloroethylene are being used as well as aqueous cleaners in several European countries as replacements for TCA and CFC-113.

Metals susceptible to oxidation (e.g., D6AC high-strength steel) and metals susceptible to embrittlement and corrosion (e.g., titanium and 7000 series

Table 32-5. Metal-Cleaning Processes
Processes are Listed in Order of Decreasing Preference

Type of production	In-process cleaning	Preparation for painting	Preparation for phosphating	Preparation for plating
		Removal of pigmented drawing compounds		
Occasional or intermittent	Hot-emulsion hand slush, spray emulsion in single stage, vapor slush degrease	Boiling alkaline, blow-off, hand wipe Vapor slush degrease, hand wipe Acid clean	Hot-emulsion hand slush, spray emulsion in single stage, hot rinse, hand wipe	Hot alkaline soak, hot rinse (hand wipe, if possible), electrolytic alkaline, cold-water rinse
Continuous high production	Conveyorized spray emulsion washer	Alkaline soak, hot rinse, alkaline spray, hot rinse	Alkaline or acid soak, hot rinse, alkaline or acid spray, hot rinse	Hot-emulsion or alkaline soak, hot rinse, electrolyte alkaline, hot rinse
		Removal of unpigmented oil and grease		
Occasional or intermittent	Solvent wipe Emulsion dip or spray Vapor degrease Cold solvent dip Alkaline dip, rinse, dry (or dip in rust preventive)	Solvent wipe Vapor degrease or phosphoric acid clean	Solvent wipe Emulsion dip or spray, rinse Vapor degrease	Solvent wipe Emulsion soak, barrel rinse, electrolytic alkaline rinse, hydrochloric acid dip, rinse
Continuous high production	Automatic vapor degrease Emulsion, tumble, spray, rinse, dry	Automatic vapor degrease	Emulsion power spray, rinse Vapor degrease Acid clean	Automatic vapor degrease, electrolytic alkaline rinse, hydrochloric acid dip, rinse
		Removal of chips and cutting fluid		
Occasional or intermittent	Solvent wipe Alkaline dip and emulsion surfactant Stoddard solvent or TCE Steam	Solvent wipe Alkaline dip and emulsion surfactant Solvent or vapor	Solvent wipe Alkaline dip and emulsion surfactant Solvent or vapor	Solvent wipe Alkaline dip, rinse, electrolytic alkaline rinse, acid dip, rinse
Continuous high production	Alkaline (dip or spray) and emulsion surfactant	Alkaline (dip or spray) and emulsion surfactant	Alkaline (dip or spray) and emulsion surfactant	Alkaline soak, rinse, electrolytic alkaline rinse, acid dip and rinse

Table 32-5. Metal-Cleaning Processes (*Continued*)
Processes are Listed in Order of Decreasing Preference

Type of production	In-process cleaning	Preparation for painting	Preparation for phosphating	Preparation for plating
		Removal of polishing and buffing compounds		
Occasional or intermittent	Seldom required	Solvent wipe Surfactant alkaline (agitated soak), rinse Emulsion soak, rinse	Solvent wipe Surfactant alkaline (agitated soak), rinse Emulsion soak, rinse	Solvent wipe Surfactant alkaline (agitated soak), rinse, electroclean
Continuous high production	Seldom required	Surfactant alkaline spray, spray rinse Agitated soak or spray, rinse[a]	Surfactant alkaline spray, spray rinse Emulsion spray, rinse	Surfactant alkaline soak and spray, alkaline soak, spray, and rinse, electrolytic alkaline rinse, mild acid pickle, rinse

[a] For complete removal of pigment, parts should be cleaned immediately after the forming operation, and all rinses should be sprayed where practical.
[b] Used only when pigment residue can be tolerated in subsequent operations.
[c] Phosphoric acid cleaner-coaters are often sprayed on the parts to clean the surface and leave a thin phosphate coating.
[d] Phosphoric acid for cleaning and iron phosphating. Proprietary products for high- and low-temperature application are available.
[e] Some plating processes may require additional cleaning dips.
[f] Neutral emulsion or solvent should be used before manganese phosphating.
[g] Reverse-current cleaning may be necessary to remove chips from parts having deep recesses.
[h] For cyanide plating, acid dip and water rinse are followed by alkaline and water rinses.
[i] Other preferences: stable or diphase emulsion spray or soak, rinse, alkaline spray or soak, rinse, electroclean; or solvent presoak, alkaline soak or spray, electroclean.
[j] Third preference: emulsion spray rinse.

aluminum) may limit the viable substitutes for hydrocarbons or oxygenated solvents for these applications.

Complex part geometries, such as blind holes, tubing, and aircraft honeycomb structures may require special equipment and procedures—including part oscillation, rotation, or vibration in the cleaner bath; ultrasonics; or high-pressure spray—to obtain acceptable cleanliness using aqueous and emulsion cleaners.

Highly carbonaceous soils (e.g., Cosmoline) and high-molecular-weight soils (e.g., paraffin or polyethylene glycol waxes) require the use of terpene hydrocarbons, naphtha blends, or spray inpingement with high-pressure surfactant/steam, solid carbon dioxide, or sodium bicarbonate.

Use of water-soluble or emulsifiable forming, stamping, machining, and cutting fluids will enhance the applicability of aqueous and emulsion cleaners as chlorinated solvent vapor degreasing and cold-cleaning substitutes.

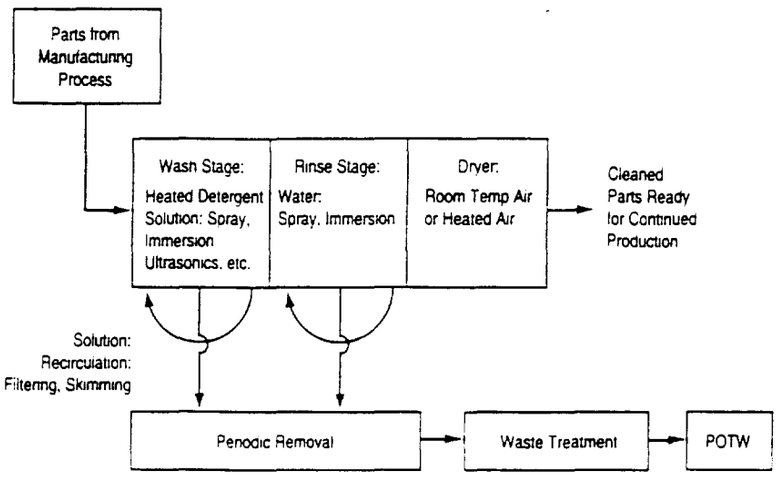

Figure 32-2. Configuration of aqueous cleaning process in the metal-cleaning industry. (*Courtesy of U.S. EPA, 1989a.*)

Manual wiping and cleanup solvents are being replaced with reduced-vapor-pressure solvent blends of 45 mmHg or less composite vapor pressure; many contain fewer HAP constituents.

Alternate wipe solvents and batch degreasers tend to be more application-specific; i.e., "general purpose cleaners" will be replaced by several materials and processes.

Operator and user techniques are more sophisticated and have lower tolerances with the substitute materials and processes as compared to the traditional solvents.

32.2.2 Further Reading and Case Histories

For further reading and case histories relevant to Sec. 32.2 topics, see Refs. 1–9.

32.3 Precision Instruments and Devices

32.3.1 Background[10]

The term *precision cleaning* is difficult to define. The following list provides an indication of the wide and varied applicability of precision cleaning.

Electronics (recording heads, solenoids, micro switches, servo motors)

Medical (heart pacemakers, contact lenses, prosthesis manufacture)

Defense (inertial guidance systems, ball bearings, hydraulic systems)

Aerospace (avionics maintenance, fuel systems, flight controls)

Precision-cleaning applications are characterized by the extremely fine level of cleanliness required to keep delicate instruments and surfaces operating effectively, as illustrated in Fig. 32-3. As Fig. 32-2 implies, precision component cleaning requires the use of more effective cleaning technologies than those traditionally employed in heavy industries, such as those discussed in Sec. 32.2, "Metal Fabrication and Finishing." The key factors that define precision cleaning are those applications in which

- Critical cleanliness standards of particulate and/or organic contaminants need to be satisfied
- Components have sensitive compatibilities

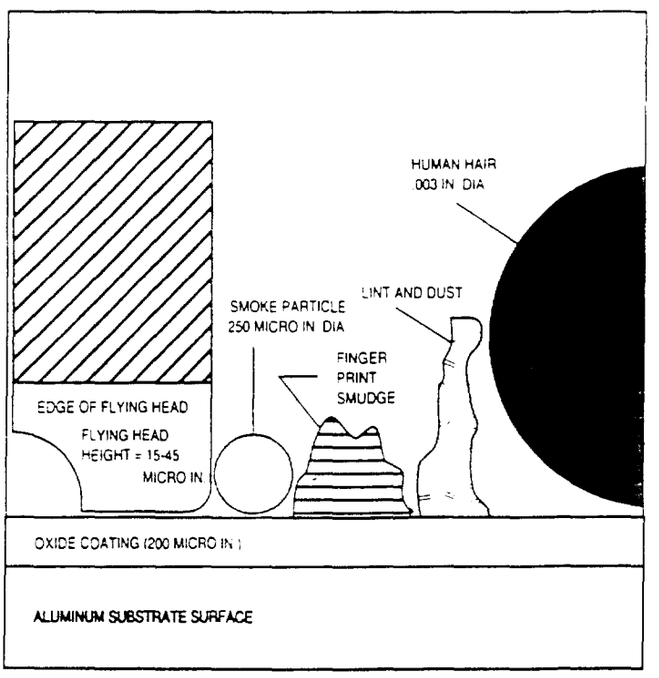

Figure 32-3. Size comparison of computer disk drive head clearance with various contaminants. (*Courtesy of Digital Equipment Corporation.*)

- Components have physical characteristics such as geometry or porosity which make dewatering crucial in the cleaning process
- Components being cleaned are costly

The necessary and desirable solvent properties include[10]

- A volatile solvent with zero nonvolatile residue
- Sufficient solvent power to dissolve organic soils
- Low surface tension to penetrate small spaces between surfaces and components
- High density to assist in displacing and suspending small insoluble particles
- Rapid drying
- Low cost
- Low toxicity
- Nonflammability

Industry has developed a strong dependence on CFC-113, CFC-113 alcohol azeotropes, and TCA as the primary precision instrumentation cleaning solvents.

32.3.2 Summary of Options and Recommendations

A number of options for precision cleaning are available. The following list[10] classifies the options as either alternative cleaning processes or alternative solvents.

Alternative cleaning processes

- Aqueous
- Semiaqueous
- Pressurized gas
- Supercritical fluids
- Plasma cleaning
- Ultraviolet/ozone

Alternate solvents

- Hydrochlorofluorocarbons (HCFCs)
- Alcohols with perfluorocarbons
- *N*-methyl-2-pyrrolidone
- Perfluoronated alkanes
- Aliphatic hydrocarbons
- Miscellaneous solvents (e.g., ketones, ethers)

Discussion here will be limited to the most widely applicable options. The documents referenced at the end of this section can be consulted to obtain greater detail on each of these materials and processes.

Aqueous. The process design and equipment selection are the key to achieving acceptable aqueous alkaline cleaning in precision applications. Immersion with mechanical agitation or ultrasonics and spray methods are those being most widely incorporated in the substitution for solvent-cleaning methods. Aqueous methods are generally superior to solvent methods in removal of inorganic, polar soils and of particulate matter. However, for high-molecular-weight oils and fluorocarbon greases, multiple cleaning steps or inclusion of cleaning-enhancement methods, such as ultrasonics, may be necessary. Among the significant concerns with aqueous cleaners are soil removal from parts with complex geometries; cleaning-material compatibility with polymers, elastomers, corrosion-sensitive substrate metals, alloys, and porous surfaces; and process control. The rinsing and drying steps are of particular concern. Equipment must be carefully designed and controlled. In addition, energy consumption, the need for high-purity water, and wastewater disposal can have a significant cost impact. Table 32-6 summarizes the advantages and disadvantages associated with each aqueous cleaning method. All of these factors should be considered carefully and within the broader context of the environmental regulatory issues described in Sec. 32.1. Figure 32-4 shows a generalized configuration of an aqueous cleaning process. This general design can also be applied to the general metal fabrication and metal-finishing applications discussed in Sec. 32.2.

Semi-Aqueous. Hydrocarbon/surfactant cleaners can either be emulsified in water and applied in a manner similar to the aqueous cleaners discussed above or they can be applied in concentrated form and rinsed with water. These methods and materials, collectively, are commonly known as *semi-aqueous cleaners*. The general advantages and disadvantages of these materials are similar to those of aqueous cleaners. Semi-aqueous methods can provide greater soil removal and emulsification of higher-molecular-weight hydrocarbon soils and greater compatibility with corrosion-sensitive materials. Semi-aqueous cleaners may pose flammability and odor concerns that must be addressed in the equipment design—e.g., terpene hydrocarbons. Semi-aqueous cleaner stability may also pose particular process control challenges, e.g., auto-oxidation, phase separation, and gelling of organic components. Figure 32-5 is a general conceptualized semi-aqueous cleaning system.

Supercritical Fluids.[n] *Supercritical fluids* (SCFs) are characterized by their existence in a critical temperature and pressure region as follows:

$$0.9 < T_r < 1.2 \qquad \text{and} \qquad 1.0 < P_r < 3.0$$

where T_r and P_r are reduced temperature and pressure, respectively. $T_r = T/T_c$ and $P_r = P/P_c$ where T and P are the actual temperature and pressure, respectively, and T_c and P_c are the critical temperature and pressure, respectively. When elevated to temperatures near or greater than the critical temperature and

Table 32-6. Advantages and Disadvantages of Aqueous Cleaning

Advantages	Disadvantages
Safety—Aqueous systems have few problems with worker safety compared to many solvents. They are not flammable or explosive. It is important, however, to consult the Material Safety Data Sheets for information on health and safety.	Cleaning difficulty—Parts with blind holes and small crevices may be difficult to clean and may require process optimization.
Cleaning—Aqueous systems can be readily designed to clean particles and films better than solvents.	Process control—Aqueous processes require careful engineering and control.
Multiple degrees of freedom—Aqueous systems have multiple degrees of freedom in process design formulation and concentration. This enables aqueous processes to provide superior cleaning for a wider variety of contamination.	Rinsing—Some aqueous cleaner residues can be difficult to rinse from surfaces. Nonionic surfactants are especially difficult to rinse. Trace residues may not be appropriate for some applications and materials. Special precautions should be applied for parts requiring subsequent vacuum deposition, liquid oxygen contact, etc. Rinsing can be improved using DI water or alcohol rinse.
Inorganic or polar soils—Aqueous cleaning is particularly good for cleaning inorganic or polar materials. For environmental and other reasons, many machine shops are using or converting to water-based lubricants and coolants versus oil-based. These are ideally suited to aqueous chemistry.	Floor space—In some instances, aqueous cleaning may require more floor space.
Oil and grease removal—Organic films, oils, and greases can be removed very effectively by aqueous chemistry.	Drying—For certain part geometries with crevices and blind holes drying may be difficult to accomplish. An additional drying section may be required.
Multiple cleaning mechanisms—Aqueous cleaning functions by several mechanisms rather than just one (solvency), including saponification (chemical reaction), displacement, emulsification, dispersion, and others. Particles are effectively removed by surface activity coupled with the application of energy.	Material compatibility—Corrosion of metals or delayed environmental stress cracking of certain polymers may occur.
Ultrasonics applicability—Ultrasonics are much more effective in water-based solvents than in CFC-113 solvents.	Water—In some applications high-purity water is needed. Depending on purity and volume, high-purity water can be expensive.
Chemical cost—Low consumption and inexpensive.	Energy consumption—Energy consumption may be higher than for solvent cleaning in applications that require heated rinse and drying stages.
	Wastewater disposal—In some instances use of aqueous cleaning may require wastewater treatment prior to discharge.

at high pressures, these compounds, which are gases at ambient temperatures, become fluids with high soil dissolution properties, high diffusivity, low viscosity, and low density. The advantages of this technology are its flexibility of application, rapidity of cleaning, and reasonable operating costs. The disadvantages include the high capital cost of designing and operating a system that

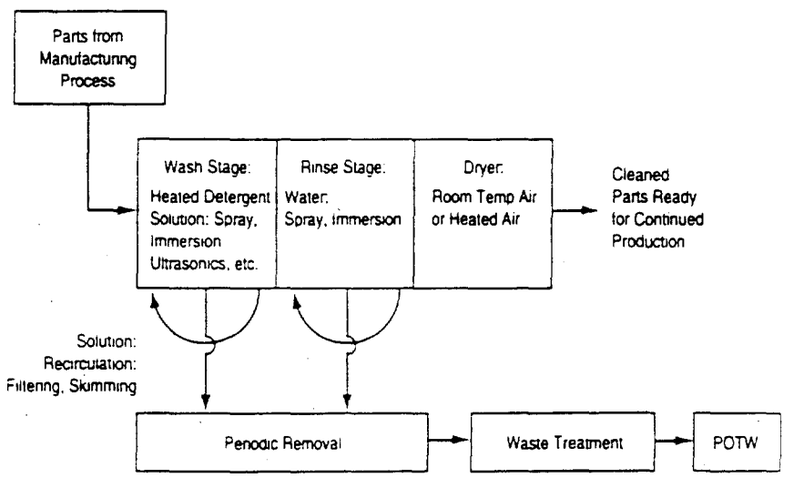

Figure 32-4. Configuration of aqueous cleaning process. (*Courtesy of U.S. EPA, 1989.*)

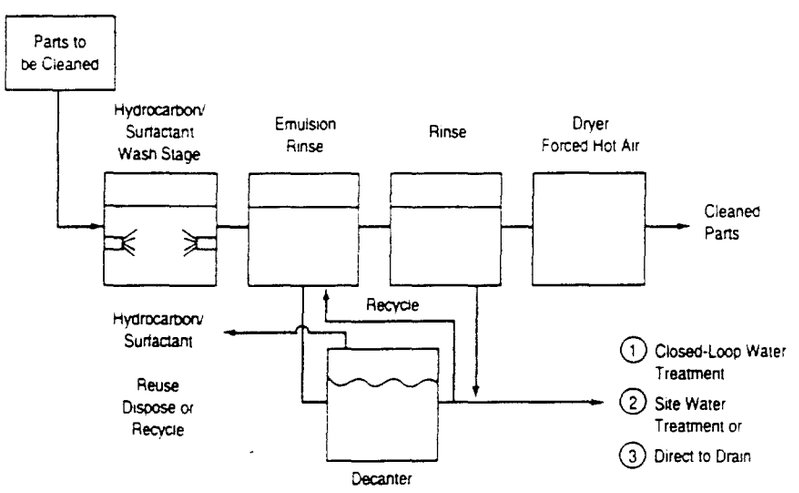

Figure 32-5. Semi-aqueous process for immiscible hydrocarbon solvent.

operates at high temperatures and pressures. These conditions may also be detrimental to the item being cleaned. Water, carbon dioxide, methane, ethane, ammonia, and ethanol are among the compounds being considered for SCF applications. Carbon dioxide has received the most investigation to date. Figure 32-6 shows a conceptualized SCF system that uses carbon dioxide.

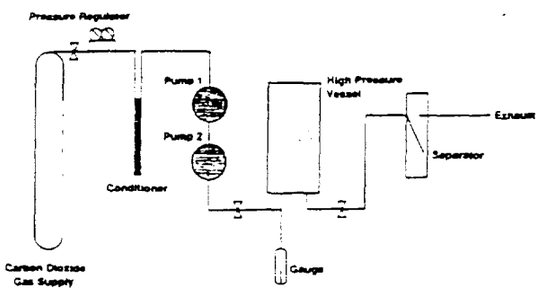

Figure 32-6. Basic model design for carbon dioxide supercritical cleaning system. (*Courtesy of Jackson, 1987.*)

Hydrochlorofluorocarbons.[10] Use of HCFCs, particularly (1) HCFC-141b and (2) HCFC-225ca/cb, have been proposed as a means of replacing CFC-113 and TCA due to their similar physical and chemical properties. In these instances, similar equipment and procedures could be employed. HCFC-141b is not approved as a vapor degreaser replacement material under SNAP and is more corrosive than CFC-113. HCFC-225ca/cb is under SNAP review. HCFC-225 ca/cb is quite expensive as compared to CFC-113 and will only be available in limited quantities. Although the soil dissolution properties and system requirements make HCFC attractive, these compounds are listed as Class II ozone-depleting compounds in the Clean Air Act Amendments of 1990. As such, they are subject to production limitations and will likely be phased out no later than the year 2030. Figure 32-7 shows an advanced vapor degreaser designed to minimize atmospheric emissions even with low-boiling-point solvents.

Alcohols with Perfluoroalkanes.[11] Alcohols have excellent soil dissolution properties for polar, polar organic, and hydrocarbon soils, particularly when heated or as a boiling liquid. However, the extreme flammability hazards associated with heated-alcohol cleaning have made this approach impractical in the past. A recently introduced technique, the use of a perfluorocarbon vapor "blanket" above heated alcohol in a cleaning system, renders the alcohol vapor nonflammable. Further, the perfluorocarbons and alcohol are relatively immiscible. Therefore, they can be used together and recovered for reuse with minimal mixing. This technology may prove useful with materials sensitive to aqueous or other solvents or with materials with complex parts geometries. However, such systems retain significant design and operating requirements. Perfluorocarbons are also expensive. For these two reasons capital and operating costs will be high.

Perfluorocarbons.[11] This group of compounds have all hydrogen atoms substituted with a fluorine atom. Thus, they are highly stable molecules. They have low toxicity and are nonflammable. However, they are very costly. Also, because they are both infrared absorbers and very stable, they have a high

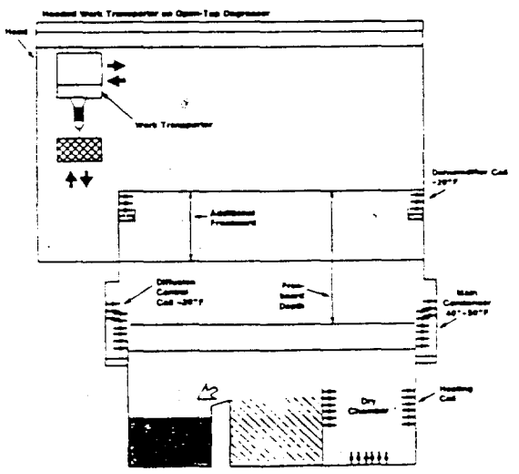

Figure 32-7. Advanced-design degreaser for use with low-boiling-point solvents. (*Courtesy of Du Pont.*)

global warming potential. Perfluoroalkanes' greatest potential application is in cleaning gyroscopes and guidance equipment that contain fluorinated lubricants and where elastomers and polymeric materials require cleaning.

32.3.3 Further Reading and Case Histories

For further readings and case histories relevant to Sec. 32.3 topics, see Refs. 1, 4, and 10.

32.4 Printed Circuit Board Manufacture and Assembly

32.4.1 Background[1]

The assembly of electronics components historically has created the need for the removal of residues from assemblies after soldering. Solder flux residues are characterized as a mixture of raw flux, flux decomposition products, reaction products between the flux components and metal oxides, and residues from soldering oils and contaminants from previous operations left on the boards.[1] CFC-113 became the prevalent defluxing and printed circuit board cleaning solvent by the late 1970s. The use of TCA and TCA-alcohol azeotropes in electronics cleaning has been less, but significant, nevertheless. No other single industry sector has been so completely affected due to the international phase-out of its two most widely used cleaning solvents. Both chemicals have

been fundamental elements contributing to product performance and reliability. The electronics industry involves a variety of substrate materials, including numerous polymeric and elastomeric materials, complex geometries, and low-tolerance configurations. The complexities of electronics cleaning will not be discussed in detail here.

32.4.2 Summary of Options and Recommendations[1]

The six primary methods for replacing the highly volatile, ozone-depleting solvents and their applicability are summarized in Table 32-7, with CFC-113 and TCA serving as benchmarks. Table 32-8 provides information on the applicability, costs, and relative strengths and weaknesses of the eight material and process combinations prevalent in the substitution for CFC-113 and TCA. The Technology and Economic Assessment Panel under the Montreal Protocol has noted the following technical trends[3] in replacing ozone-depleting solvents in electronics manufacturing:

- No clean soldering is the first choice to eliminate CFC-113 and TCA. It can decrease costs, avoid hazardous solvent waste disposal, and if operated under controlled atmosphere, minimize dross containing lead oxide. Some manufacturers report increased production efficiency and improved reliability.
- For those applications where cleaning remains necessary, aqueous methods predominate.

Table 32-9 provides a comparison of aqueous-cleaning systems ranging from batch dishwasher types that are preferred by small specialty shops to convey-

Table 32-7. Cleaning Options to Replace CFC-113 and Methyl Chloroform

	No clean	Aqueous saponified underbrush	Semi-aqueous underbrush	Aqueous spray	Aqueous saponified spray	Semi-aqueous spray	CFC-113 and methyl chloroform
Rosin flux—PTH*	X	X	X		X	X	X
Water-soluble flux—PTH				X	X	X	
Synthetic activated flux—PTH						X	X
Rosin flux—SM†	X				X	X	X
Water-soluble paste—SM					X	X	
Rosin flux—mix top and bottom SM and PTH	X				X	X	X
Water-soluble flux—mix top and bottom SM and PTH				X	X	X	
Low-solids flux	X						
Controlled-atmosphere soldering	X						

*PTH=plated through hole
†=Surface mount.
SOURCE: Ref. 1.

Table 32-8. Summary Comparison of Cleaning Processes

Issue	Hydrocarbon surfactant			Saponified aqueous			Aqueous	
	Underbrush	In-line spray	Batch	Underbrush	In-line spray	Batch	In-line spray	Batch
Equipment cost (mid-range)	$50,000	$160,000	$40,000	$50,000	$100,000	$40,000	$100,000	$40,000
Floor space requirement (minimum) (ft^2)	100	500	40	100	200	40	200	40
Applicable to surface mount technology (SMT)	No	Yes	Yes	No	Yes	Yes	Limited	Limited
Component compatibility issues	Low	Moderate	Moderate	Low	Moderate	Moderate	High	High
Defect rate	Average	Average	Average	Average	Average	Average	Lower	Lower
Throughput rate (average) (ft/min)	5	9	Variable	5	5	Variable	5	Variable
Complexity of installation	Low	High	Low	Low	Medium	Low	Medium	Low
Wastestream handling	Necessary	Necessary	Necessary	Necessary	Necessary	Necessary	Necessary	Necessary
Health and safety issues	Must be evaluated	Must be evaluated	Must be evaluated	Must be evaluated	Must be evaluated	Must be evaluated	Must be evaluated	Must be evaluated
Process flexibility	Low	High	High	Low	Medium	Medium	Low	Low
Idle-time cost	Low	Medium	Low	Low	High	Low	High	Low
Processing cost per square foot compared to CFC-113	5×	4×	3×	4×	2×	1×	1×	1×

Table 32-9. Comparison of Aqueous Process Machine Types*

	Brush	Dishwasher	High-throughput	Tank	Conveyorized
Principle	Underbrush	Spray	Spray	Immersion	Spray
Water soluble (W/S) flux	No	Yes	Yes	Yes	Yes
Saponifier	Possibly	Yes	Yes	Yes	Yes
Hydrocarbon/surfactant (HC/S) wash phase	Possibly	Yes	Yes	Yes	Yes
Surface mounted device (SMD)	No	Possibly	Yes	Yes	Yes
Throughput ($m^2 \cdot h^{-1}$)	10–40	1–2	5–25	2–25	5–50
Water conservation ($L \cdot m^{-2}$)	20–50	25–40	8–15	10–50	10–50
Electricity conservation	0.5–1	1–1.5	0.5–1	0.5–1.5	1–2
Ultrasonics	No	No	No	Possibly	No
Cleaning	Mediocre	Very good	Very good	Good to very good	Mediocre to very good
Drying available	Mediocre	Mediocre	Very good	Variable	Variable
Floor space (m^2)	2–3	2–3	6–10	10–20	10–20
Handling conveyor	Conveyor	Manual	Manual/robot	Hoist	Conveyor
Flexibility	Poor	Excellent	Excellent	Excellent	Poor

*The information given in this table is typical of machines available on the international market. The performance of individual machines may vary considerably and potential users are advised to check with their supplier as to the accuracy of this information under their specific conditions of use.

orized systems that are better suited for major circuit-manufacturing centers. Semi-aqueous cleaners, particularly terpene hydrocarbons, were among the substitutes initially considered and implemented by many companies wishing to make rapid transition from ozone-depleting solvents. Semi-aqueous cleaners appear to be more limited in application than aqueous methods due to cost associated with explosionproof equipment, waste disposal, and wastewater treatment.

32.4.3 Further Reading and Case Histories

For further reading and case histories on Sec. 32.4 topics, see Refs. 1, 3, and 11.

32.5 Maintenance Activities

32.5.1 Background

Maintenance activities at industrial and manufacturing facilities are defined here as the cleaning of products during rework or refurbishment and cleaning of tooling, equipment, work areas, and work surfaces associated with general factory housekeeping. Historically, many facilities used "general purpose cleaners" for both production and maintenance activities. Thus, the solvents listed in Table 32-1 serve as the historical baseline in this portion of the discussion as well.

32.5.2 Summary of Options and Recommendations

The general recommendations made in Sec. 32.2,, "Metal Fabrication and Finishing," apply to factory maintenance activities and rework or refurbishment of parts. However, the soils encountered during maintenance and repair of mechanical devices in products and equipment (motors, compressors, engines, vehicle wheels, etc.) tend to be oxidized, solidified, or reacted; are more carbonaceous in nature; and contain more insoluble particulate matter and salts than encountered during the manufacturing process. In these situations, mechanical impingement, such as plastic media blasting; high-pressure aqueous alkaline cleaner spray; high-pressure surfactant/steam spray; terpene hydrocarbon (particularly D-limonene) wipe and immersion; C7–C12 hydrocarbon wipe and immersion; C4–C6 acetate wipe; and blends of the aforementioned organic solvents as wipe and immersion cleaners offer the greatest degree of soil displacement, emulsification, or dissolution. Special attention must be paid to coated parts and composite materials to ensure that coatings and other sensitive components—e.g., gaskets, seals, and plastic devices—are not adversely affected by the cleaning material or process. Parts with complex geometries may have special drying considerations. In most cases, additional labor time and

increased user diligence will be required when any of the above materials and processes are substituted for high-volatility solvents listed in Table 32-1.

32.6 Nonmetallic Materials

These materials include composites (e.g., graphite-epoxy), elastomeric materials, fiberglass, and thermoplastic and thermoset polymers.

32.6.1 Summary of Options and Recommendations

Composite materials typically may be cleaned using the alternatives discussed in Sec. 32.2 and 32.3. However, special care must be taken to perform prolonged, sensitive-exposure bench tests of composites in the candidate cleaning materials in order to identify any subtle embrittlement and corrosion effects. Elastomeric materials vary in their resistance to aqueous solutions. The literature should be consulted to identify situations involving sensitive elastomers. Low-vapor-pressure solvents may cause significant swelling to elastomers, as the slow-evaporating solvent is absorbed into the surface and requires substantial amounts of time for residual solvent to desorb and evaporate. This also increases the potential for irreversible damage to the elastomer. Certain polymeric materials, such as polycarbonate and methacrylate and other acrylics, tend to craze or crack when exposed to low-volatility ester, acetate, and ketone solvent liquids. In cases where sensitive parts are encountered, the use of a higher-volatility, less aggressive solvent is unavoidable. The most benign alternates include methanol, ethanol, isopropanol, acetone, and aqueous solutions of these solvents.

32.7 Adhesives, Coatings, Inks, and Aerosols

32.7.1 Background

Table 32-10[1] lists the common adhesive solvents. It is estimated that 48 percent of the U.S. coatings and inks market in 1986 was solvent-based formulations. TCA has been a popular aerosol propellant, with flammable hydrocarbons such as propane, butane, and pentane also used.

32.7.2 Summary of Options and Recommendations[1]

Alternates to solvent-based adhesives include powder coatings, hot-melt adhesives, radiation-cured adhesives, moisture-cured adhesives, water-based solu-

Table 32-10. Physical Properties of Common Adhesive Solvents

Solvent	Flashpoint, open cup (°C)	Flammable limit in air (volume % at 25 °C) Upper	Lower	Water soluble in 100 g solvent (g)	Density (g/L at 20°C)
TCA	NF*	12.5	7.5	0.05	1.314
Methylene chloride	NF	22.0	14.0	0.17	1.316
Toluene	7.22	7.0	1.3	0.05	0.870
N-hexane	−27.8	6.9	1.25	0.01	0.678
MEK	−5.6	11.5	1.81	11.80	0.804
Ethyl acetate	−2.2	11.0	2.25	3.3	0.900

*NF=no flashpoint.
SOURCE: Ref. 1.

Table 32-11. Summary of Substitute Solvents for TCA in Aerosols

	Major product applications			Performance factors	
	Automotive and industrial products	Pesticides	Household products	Flammability	Density
TCA	X	X	X	None	1.32
Substitute solvents					
Petroleum distillates	X	X	X	High	0.75
Aromatic hydrocarbons	X		X	High	0.87
Alcohols	X	X		High	0.80
Ketones	X		X	High	0.81
Water systems	X	X	X	Low to none	1.00
Dimethyl ether (DME)		X		High	0.66
HCFC propellants*	X	X	X	None	1–1.21

*Includes HCFC-22 and HCFC-142b.
SOURCE: Ref. 1.

tions (a latex, or emulsion), high-solids adhesives, and other solvent-based adhesives, such as acetone, ethyl acetate, heptane, and toluene. Alternative coatings and inks becoming commercially available include powder coatings, water-based coatings, and high-solids formulations. Table 32-11 summarizes substitute solvents for aerosols.

32.8 Material and Process Change Considerations

The most vulnerable point in the process of changing any fundamental manufacturing activity, such as cleaning, is the transition into the factory setting. This activity is the least predictable, the least rational, and cannot be totally

simulated in bench or pilot testing. Parameters to investigate, when considering a cleaning material and process change, include equipment and operating parameter variability during scale-up; agitation and foaming in aqueous cleaning processes; floor space, throughput limitations, rinsing, and residues with aqueous and low-volatility solvents in batch or conveyorized systems; drying; energy consumption; labor requirements per unit product; operator skills; and capital and operating costs. The following general conclusions are derived from experience gained in a major aerospace manufacturing facility and may be worthy of consideration:

- A "systems approach" is essential for a successful technology.
- An integrated product team of representatives from all affected functions should be formed at the beginning of the project.
- The users and operators of the material and/or system should lead the transition.
- Much time, energy, innovation, and perseverance is required during the transition.
- Material and process change requires a thorough understanding of the system performance requirements and of the history of the existing materials and processes.
- It is difficult to generalize across industry sectors.

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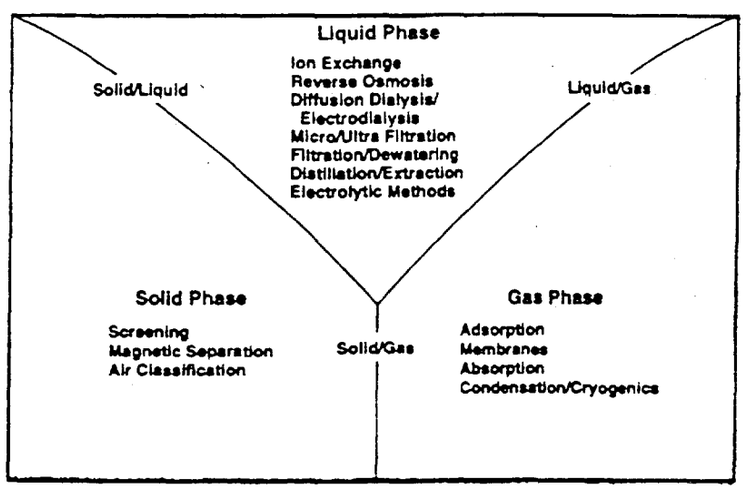
Possible Substitutes for Hazardous Chemicals

Procedure	Hazardous chemical	Substitute
Glassware cleaning	Chromic-sulfuric acid solutions	Detergents, enzymatic cleaners
Qual. test for halide ions	Carbon tetrachloride	Cyclohexane
Organic synthesis	Chromate ion	Hypochlorite ion
Qual. test for heavy metals	Sulfide ion	Hydroxide ion
Measurement of vapor pressure-temperature by isotensiscope	Carbon tetrachloride	Isopropyl alcohol
Determination of molecular weight by freezing point lowering methods	Benzene	Cyclohexane
Temperature	Mercury thermometers	Red liquid thermometers
Storage of biological specimens	Formaldehyde	Ethanol or other preservative
Organic synthesis, etc.	Ethyl ether	Methyl t-butyl ether
In-phase change and freezing point depression	Acetamide	Stearic acid

Source: Freeman, Harry; Industrial Pollution Prevention Handbook

Key separation technologies in pollution prevention.



Source: Freeman, Harry; Industrial Pollution Prevention Handbook

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Table 36-7. Examples of By-Product Recovery Technologies

Technology	Description	Applications
Evaporation	Removal of solvent as a vapor from a solution or slurry. The vapor and/or the residue may be the recovered by-product.	Extract proteins Concentrate metals
Selective ion exchange	Uses a solid phase containing bound groups that carry an ionic charge, either positive or negative, with free ions of the opposite charge that can be displaced. Chelating ion exchange resins have high selectivity for certain cations.	Metal recovery from plating solutions Concentration of ammonia
Reverse osmosis	Pressure overcomes the osmotic pressure so that water passes a semipermeable membrane and dissolved salts are rejected.	Recover pesticides Concentrate salts Acid recovery
Ultrafiltration	Filtration using membranes with small pore size. Can be used to filter large soluble molecules or colloidal solids.	Recover pesticides
Biotechnology	Microbes perform specific enzyme mediated reactions.	Methane formation by anaerobic decomposition of organic compounds Concentration of precious metals
Solvent extraction	Two immiscible liquid phases are brought into contact for the transfer of one or more components.	Extract valuable organic compounds from water Concentrate soluble metals
Distillation	The separation of the liquid mixture by partial vaporization and separate recovery of vapor and residue.	Alcohol recovery Solvent purification
Selective precipitation	Desired ions are precipitated by control of pH or counter ions.	Plating solutions
Electrodialysis	An electromotive force is used to transport ionized materials through an ion-selective, semipermeable membrane.	Concentrating brine solutions Recover acids Recover metals
Crystallization	Formation of high-purity crystalline solids from liquid or vapor.	Mineral recovery

Source: Freeman, Harry; Industrial Pollution Prevention Handbook

Table 36-8. Application for Wastewater Reuse and Potential Constraints*

Applications for wastewater reuse	Potential constraints
Agricultural irrigation	
Crop irrigation	Surface and groundwater pollution if not properly managed
Commercial nurseries	
Landscape irrigation	Marketability of crops and public acceptance
Park	Effect of water quality, particularly salts, on solids and crops
School yard	
Freeway median	
Golf course	Public health concerns related to pathogens (bacteria, viruses, and parasites)
Cemetery	
Greenbelt	Controls may be needed for use area, including buffer zones, consequently resulting in high user costs
Residential	
Industrial reuse	
Cooling tower makeup water	Constituents in reclaimed wastewater relating to scaling, corrosion, biological growth, and fouling
Once-through cooling water	
Boiler feed water	Public health concerns, particularly aerosol transmission of pathogens in cooling water
Process water	
Groundwater recharge	
Groundwater replenishment	Organic chemicals in reclaimed wastewater and their toxicological effects; TDS, nitrates, and pathogens in reclaimed wastewater
Saltwater intrusion control	
Subsidence control	
Recreational/environmental uses	
Lakes and ponds	Health concerns about bacteria and viruses
Marsh enhancement	Eutrophication due to nitrogen and phosphorus in receiving waters
Streamflow augmentation	
Fisheries	
Snowmaking	Toxicity to aquatic life
Nonpotable urban uses	
Fire protection	Public health concerns about pathogens transmitted by aerosols
Air-conditioning	
Toilet flushing	Effects of water quality on scaling, corrosion, biological growth, and fouling
	Cross-connections
Potable reuse	
Blending in water supply	Constituents in reclaimed wastewater, especially trace organic chemicals and their toxicological effects
Reservoir	
Pipe-to-pipe water supply	
	Aesthetics and public acceptance
	Health concerns about pathogen transmission, particularly viruses

*Adapted from Metcalf & Eddy, Inc., *Wastewater Engineering: Treatment, Disposal, and Reuse*, 3d ed., New York, 1991.

Source: Freeman, Harry; Industrial Pollution Prevention Handbook

Table 36-13. Applicable Treatment Technologies for Wastewater Reuse

Treatment technology	Description	Applications	Limitations
Reverse osmosis	Uses the principles of osmosis and differences in pressure to separate dissolved salts in a solution from water by filtering the wastewater through a semipermeable membrane.	Removal of BOD, COD, TSS, NH_3-N, TDS, and phosphorus	Cost Scaling pH and temperature sensitivity Pretreatment may be required Concentrate may require treatment or disposal
Electrodialysis	Electrodialysis concentrates or separates ionic species contained in a solution by passing the solution through semipermeable ion-selective membranes.	Removal of TDS and recovery of metal salts	Chemical precipitation on membrane Pretreatment may be required Cost
Ultrafiltration	Similar to reverse osmosis, ultrafiltration uses porous membranes to remove dissolved and colloidal materials from solutions; however, ultrafiltration operates at lower pressures and is generally limited to removing larger molecules.	Removal of TDS, turbidity, and oil	Cost Scaling pH and temperature sensitivity Pretreatment may be required
Ion exchange	Ion exchange removes specific ions from a solution by exchanging them with ions bound to a specially formulated resin. The resin requires backwashing and regeneration once its capacity has been reached.	Removal of TDS and toxic metal ions; and reduction of hardness by removing calcium and magnesium ions	Spent resins and regenerants (i.e., acid, caustic, or brine) must be disposed High concentrations of suspended solids can reduce the efficiency of the resin
Activated carbon	The activated carbon process uses either granular or powdered carbon to treat wastewater by adsorbing many organic and inorganic compounds. Once the capacity of the carbon has been reached, it must be regenerated.	Removal of many organic and inorganic compounds Treats organic wastes (with high boiling points, low solubility, and polarity), chlorinated hydrocarbons, and aromatics Captures volatile organics in gas mixtures	Cost as a function of the frequency of carbon regeneration Contaminant concentrations should be less than 10,000 ppm Suspended solids less than 50 ppm Dissolved inorganics and oil and grease less than 10 ppm

Source: Freeman, Harry; Industrial Pollution Prevention Handbook

Table 36-13. Applicable Treatment Technologies for Wastewater Reuse *(Continued)*

Treatment technology	Description	Applications	Limitations
Sedimentation	Sedimentation is a settling process that allows heavier solids to separate from a solution by gravity.	Removal of solids that are more dense than water	Not suitable for wastewaters consisting of emulsified oils
Filtration	Filtration separates and removes suspended solids from a solution by passing the solution through a porous medium (e.g., fabric, screen, granular material)	Dewatering sludges and slurries Removal of suspended solids from liquids Pretreatment to remove solids to prevent clogging of subsequent treatment devices (e.g., ion exchange, reverse osmosis, carbon adsorption)	Not suitable for reducing toxicity of the wastewater Not suitable for gelatinous solids Limitations on suspended solids concentration of liquids
Evaporation	Evaporation is a physical separation process in which energy is applied to volatilize a solution, thereby separating a liquid from dissolved or suspended solids.	Treatment of hazardous wastes Treatment of solvent wastes with nonvolatile constituents (e.g., oil, grease, polymeric resins, paint solids) Separation of dissolved and suspended solids	Effectiveness depends on the volatility of the solution Cost
Dewatering	Dewatering includes any of a number of physical processes (e.g., vacuum filtration, sludge drying, belt filter press) used to reduce the moisture content of sludges.	Reducing the moisture content of sludges	Limitations depend on the dewatering process used for a particular type of sludge

TABLE A-1 - INDUSTRIAL WASTE MINIMIZATION OPPORTUNITIES

INDUSTRY	SIC	PERCEIVED NEED	PROPOSED SOLUTIONS IF KNOWN	STATUS	POTENTIAL IMPACTS OF CHANGE	TRANSFER POTENTIAL
Textile Dyes and Dying and Finishing	226	Replace toxic dyes	Use less toxic chemicals	Ongoing by dye manufacturers	Less toxic wastes at manufacturer	limited due to confidentiality
		Replace toxic finishing agents	Substitute products	Ongoing where possible	Less toxic wastewater (& products sometimes)	limited
		Scouring agent recovery	Purify & recycle by hyperfiltration achieves source reduction	Extensive R&D by Porter/ Clemson U.	Less waste to neutralize (caustic)	limited, but concept can be used more broadly
		Dye recovery/recycle	Recycle by membrane processes	Some use- requires large volume to be cost effective	Less color (dye) waste to treat	limited by plant size, dye
		Solvent Finishing	Re-examine cost, efficiency, minimize wastewaters	No work at this time	Could allow/require closed loop to control solvent loss/ emissions	conceptually '-reverses usual approach away solvents
Wood Preserving	2491	Replace copper-chromate arsenate (CCA) treatment	Alternate chemical preservatives, such as copper naphthenate (CuN)	being considered	Eliminate potential long-term effects from CCA, but effects of CuN unknown	limited
Pulp and Paper	26	Replace chlorine bleach (dioxin generation?)	Use of chlorine dioxide bleaching systems	Limited Implementation Demonstration may be helpful	Reduced organochloro wastes	within industry primarily

TABLE A 1 - INDUSTRIAL WASTE MINIMIZATION OPPORTUNITIES

INDUSTRY	SIC	PERCEIVED NEED	PROPOSED SOLUTIONS IF KNOWN	STATUS	POTENTIAL IMPACTS OF CHANGE	TRANSFER POTENTIAL
		Waste paper deinking improvements sludge reclamation/reuse	Some means of using sludges, or minimizing volumes	Plants in operation, very capital intensive	Reduce deforestation Reduce solid waste	extensive in industry
		Quality degradation in recycled paper	Additives, chemical reactions to restore strength properties	No R&D known	Allow greater use of recycled pulp in products	extensive within industry; confidentiality question
		Increased ability to recycle coated stock	Find uses for TiO2, clays, etc. by-prod. Both source reduction and recycle	No specific R&D	Greatly expand recycled pulp sources	extensive in industry
		Wood by-products use, hemicellulose, lignin, etc.	Use as raw materials for chemical processes replacing other starting materials	Extensively studied but few uses found	50% of tree not currently used, except as fuel	extensive in industry; proprietary
Printing	275	Replace oils called VOC's, metallic pigments	New formulas by ink manufacturers; source reduction	Being implemented slowly	Eliminate VOC's and metals in solid waste AND in ash from incinerator	limited and slowly in industry
		Solvent Recovery - Flexography	Improved solvent recovery systems by adsorption, condensation	Costly systems are available, including one using nitrogen in a closed system	Reduce fugitive VOC's, need for incineration drying oven gases	slowly because of emissions requirements

TABLE A-1 - INDUSTRIAL WASTE MINIMIZATION OPPORTUNITIES

INDUSTRY	SIC	PERCEIVED NEED	PROPOSED SOLUTIONS IF KNOWN	STATUS	POTENTIAL IMPACTS OF CHANGE	TRANSFER POTENTIAL
		Solvent free (water-based) printing	New ink formulae needed UV - UV curing inks	Some use in flexo printing; probably not suitable for offset printing	Eliminate VOC's	slow and limited potentially in other industries
		Improved silver (plate) recovery	New technology of silver recovery	None available, but even more extensive use of known tech. would be beneficial	Reduce silver discharge in wastewaters	limited to photographic and x-ray
		Minimize start-up/shutdowns wastes: paper, ink, solvents (cleaning)	Increased automation Demonstration of cost benefits would be helpful	Implemented, but not broadly	Reduce "make-ready" paper, ink, roller cleaning	slowly because of cost
		Solvent-laden rag management	On-site cleaning of rags, recycle	Equipment does exist, not widely used on site, except in large plants	Reduce VOC (fugitive) emissions	extensive
Chemical (Organic)	282, 2869	Improved separations (solvents, salt by-products sale/use)	Membrane, IX	generally known	reduced waste volumes	Yes-except for confidentiality

TABLE A-1 - INDUSTRIAL WASTE MINIMIZATION OPPORTUNITIES

INDUSTRY	SIC	PERCEIVED NEED	PROPOSED SOLUTIONS IF KNOWN	STATUS	POTENTIAL IMPACTS OF CHANGE	TRANSFER POTENTIAL
		Solvent substitutions	Replace VOCs with "exempt" solvents, water	specific examples available	eliminate waste, may in/decrease reaction efficiency	generally
		Accelerated reaction rates	Improved catalysis, ultrasonics, Hi energy radiation	ongoing in R&D	fewer by-products. reduced reagent needed to "drive" reactions	in general sense
Chemical (Inorg.)	281	Improved separation leading to source reduction or by-product recycle	Membranes, Ion exchange	generally known; specific implementation less common	Increased product yield-little eco. impact Could allow solvent (usually water) to be reused	Yes-and to other industries
Plastics	821	Recovery of CFC, methylene chloride blowing agents	Absorbents, Condensation	Being investigated	Reduce ozone layer damage. Cost benefit as prices skyrocket	high in industry also to users (e.g., refrig. auto)
		Replace CFC blowing agents	Use of other/safer HCFC's Use of CO2 Eliminate blowing agent	All being investigated at R&D to full scale	Minimize ozone layer damage; more costly	high in industry limited in other industries
		Scrap foam plastics - increase compaction in collection-reduce use of virgin plastics	Melt in collection. Dissolve in solvent to "dope"	Mobil melt process being studied	Improve cost effectiveness of scrap recovery	high in industry limited in other industries

TABLE A-1 - INDUSTRIAL WASTE MINIMIZATION OPPORTUNITIES

INDUSTRY	SIC	PERCEIVED NEED	PROPOSED SOLUTIONS IF KNOWN	STATUS	POTENTIAL IMPACTS OF CHANGE	TRANSFER POTENTIAL
		Scrap plastic - segregation before recycle	---	---	Increase value of recycleable plastics	high in industry limited in other industries
		Scrap plastic - improve compatibility of dissimilar materials in mix	Chemical compatibilizers	R&D underway	Allow unsegregated reuse	high in industry limited in other industries
		Depolymerization-source reduction	Chemical solvolysis to monomers	Very little R&D seems to be underway	Recovery of various condensation polymers (polyester, nylon)	unknown, limited
		Biodegradable plastics as product substitutes	Starch derived plastics	Products available	Question whether they offer real enviro benefit or are just not visible in landfills	limited
Pharmaceuticals	283	Improved separations (e.g., solvents)	Membranes,	generally known	Reuse of recovered material unlikely beyond prevailing rate	confidentiality problem
		Solvent substitutions	Replace RX solvents	ongoing to extent poss.	Minimize environ. impact, potential liability	limited; confidentiality
Paint Mfg. (and application)	285	Broader range of water-based" paints, varnishes	More water-based products	Moving inexorably forward	Reduced VOC's, solvent wastes, POORER PRODUCTS NOW	limted by confidentiality

TABLE A-1 - INDUSTRIAL WASTE MINIMIZATION OPPORTUNITIES

INDUSTRY	SIC	PERCEIVED NEED	PROPOSED SOLUTIONS IF KNOWN	STATUS	POTENTIAL IMPACTS OF CHANGE	TRANSFER POTENTIAL
		Cleanup solvent reuse, incorporation in products	"Scheduled" operations to maximize reuse	In wide use, but may benefit from a plant demo	reduced solvent wastes	high
		Use of "Exempt" solvents instead of photo-reactive	Use of vernonia oil soybean oil	R&D underway in CA	Hi quality low/no VOC product will be available	some - but will be very product specific
		Product life cycle improvements-reduces need for new products	Investigate different coatings, platings, metals as means of optimizing "coating" protection to use (also consider under Metal Finishing)	New idea, some R&D may be underway in a general sense	Could change the way industry and the public look at products	potentially high
		Improved paint stripping - using no VOC's, caustic, or recycling agents	Compare all techniques caustic, solvent, blasting (sand, steel, plastic shot)	All in wide use; comparison of wastes, costs may be useful	Lower VOC's, caustic wastes, solid waste	high in industry limited in other industries
		Improved application technology to reduce material consumption and emissions	High solids coatings, electrostatic, melt, etc.	Increasing in use	Eliminate, reduce VOC's	high in industry limited in other industries
			Low pressure/High volume spray gun	Increasing in use	Reduced paint use Reduced VOC's and particulate emissions	high in industry limited in other industries

TABLE A-1 - INDUSTRIAL WASTE MINIMIZATION OPPORTUNITIES

INDUSTRY	SIC	PERCEIVED NEED	PROPOSED SOLUTIONS IF KNOWN	STATUS	POTENTIAL IMPACTS OF CHANGE	TRANSFER POTENTIAL
			NICARB (CO2-carrier)	Being developed by UCC; demonstration may be useful	Reduced VOC 30-70% Reformulation required	unknown; limited
		Improved VOC collection from conventional spray, other application methods	Small(er) scale carbon or condensation systems for VOC capture/recovery	No work underway	Reduce VOC's Reduce solv. purchases Minimize use of incineration	smaller facilities particularly could benefit; other industries too
Ink Mfg.	2893	Recovery of waste/excess ink	Small scale filtration units needed	In use by some larger plants	Eliminate disposal of inks/solvents	limited - by perception
		Ink tub clean out	Solvent cascade/reuse Demonstration may help acceptance	Extensively practiced	Minimize solvent wastes to dispose	extensive
		Water based inks as substitutes for VOC-systems	Limited application, certain segments of printing industry very resistant - new printing systems will be needed	Limited application for specific printing needs	Eliminate VOC's	limited

TABLE A-2 - INDUSTRIAL WASTE MINIMIZATION OPPORTUNITIES

INDUSTRY	SIC	PERCEIVED NEED	PROPOSED SOLUTIONS IF KNOWN	STATUS	POTENTIAL IMPACTS OF CHANGE	TRANSFER POTENTIAL
Petroleum Refining	291	Improved location of productive wells	Unknown beyond the industry's already extensive efforts	R&D, constantly	Minimize dry holes, muds, etc.	limited by confidentiality in industry
		Improved drilling muds; less toxic	"	"	Reduced toxicity of muds	limited by confidentiality in industry
		Enhanced oil recovery from sands, muds, etc.	"	"	Cleanup of existing wastes, increase yield	limited by confidentiality in industry
		Oily water separ. Emulsion breaking; Salt removal; oil to feedstock	Improved hardware and fundamental studies on O/W separation. Possible multi-step processing	...	Discharge of cleaner water or reuse of water. Recycle of oil	only limited by confidentiality Widespread if public domain
		Tank bottom reuse	Convert to usable products, e.g., coke	Known may not be cost effective currently	Eliminate waste Increase yield	limited by confidentiality Some if public domain
		Spilled Oil Recovery and Prevention	Extensive EPA R&D underway	R&D ongoing	Eliminate contamination; recycle of product	high
Steel Industry		Pollution control from coke making	Dry quenching of coke	In use outside U.S.	Eliminate suspect carcinogen particulates, VOC's, etc.	limited and slow

TABLE A-1 INDUSTRIAL WASTE MINIMIZATION OPPORTUNITIES

INDUSTRY	SIC	PERCEIVED NEED	PROPOSED SOLUTIONS IF KNOWN	STATUS	POTENTIAL IMPACTS OF CHANGE	TRANSFER POTENTIAL
		Tar Decanter Sludge reuse	Return to oven	Under investigation	Eliminate listed hazardous waste	none
		Electric Arc Furnace (EAF) dust reuse	Pelletize dust	R&D underway	Eliminate hazardous waste	good if successful-within industry only
		EAF waste acid management-both source reduction and recycle	Recovery CaF2 as raw material	Proposed, probably not implemented	Eliminate waste sludge solids, and purchase of virgin fluorspar	limited, based on plant design
		Pickling acid management and recovery	New membrane technology; distillation	New product/process from Allied	Eliminate need to neutralize, dispose of sludges	extensive if cost effective
Non-ferrous Metals	333	Minimize/eliminate SOx from smelting	Hydrometallurgical chemical conversion of MySx to MyOx	Very limited R&D underway (e.g., Pb from batteries)	Eliminate/reduce major air pollutant	extensive also steel
		Eliminate use of coke in smelting	Alternate pyrometallurgical processes using coal or other reductants	Processes in various stages or development outside U.S.	Eliminate major air, water and solid waste problems	extensive also steel
		Arsenic dust removal from smelter emissions	Ore beneficiation	Limited R&D underway	Allow greater recycle of dust rich in metal	extensive in industry; limited elsewhere

TABLE A-1 INDUSTRIAL WASTE MINIMIZATION OPPORTUNITIES

INDUSTRY	SIC	PERCEIVED NEED	PROPOSED SOLUTIONS IF KNOWN	STATUS	POTENTIAL IMPACTS OF CHANGE	TRANSFER POTENTIAL
		Improved recovery of Al from low grade bauxite and red mud waste	Physical (and chem.) ore beneficiation	Limited R&D over many years	Reduce ore, mud wastes	extensive in industry; limited elsewhere
		Aluminum pot-liner management	Various procedures being investigated for Al recovery, cryolite recovery	Extensive R&D underway to meet anticipated regulations	Probably only small impact on final wastes (CN , F)	extensive in industry; limited elsewhere
		Casting mold-sand reuse	Reprocessing has been considered	Some work underway	Significant reduction in disposed sand, often hazardous	extensive in industry; limited elsewhere except possibly steel
Metal Finishing (Electroplating)	347	Eliminate cyanide baths and rinses	Non-CN plating for Cd, Ni	R&D underway; product quality in question	Eliminate CN wastes	medium potential in industry limited elsewhere
		Improve recycle ability for CN-plating baths and rinses	Improved salt removal e.g., using membrane, IX, evaporative tech.	No evidence of R&D	Allow continued use of "best" technology Reduce frequency of replacement	widespread in industry, limited elsewhere
		Improvements in ancillary processes that generate sludges and water wastes	Improved brighteners, etc. Improved recov./recycle of brighteners, acids, etc.	No organized R&D found-most R&D emphasis on metals and CN	Reduce bath replacement frequency	widespread in industry, limited elsewhere

TABLE A-7 - INDUSTRIAL WASTE MINIMIZATION OPPORTUNITIES

INDUSTRY	SIC	PERCEIVED NEED	PROPOSED SOLUTIONS IF KNOWN	STATUS	POTENTIAL IMPACTS OF CHANGE	TRANSFER POTENTIAL
		Replace Cr VI with Cr III in bright Cr plating	Improve color of Cr III finish. Demonstrate equivalence	Some use, some R&D	Minimize Cr VI wastes that require treatment as hazardous	extensive/medium in industry, none elsewhere
		Alternate coatings	Ion deposition, painting, plastic coating, material substitution	Some R&D on deposition, very little R&D done on relative impacts of alternate coatings, materials	Extensive replacement of heavy metals possible-but with possible wastes from alternate "coatings"	limited in the short term
		By-product utilization in place of new manufacture	Alum by-product from anodizing wastes	R&D at Georgia Tech.	Eliminate high volume Al waste	unknown
		Bath and rinse water recovery	Electrodialysis	Process seems not to have achieved its potential	Reduce discharge, treatment; increase bath life	unknown; possibly some in inorg. chem industry
Electronics	3764	Metals removal (e.g., printed circuit boards)	Conventional/innovative metal precipitation recovery	Well known, widely used for disposal, very limited reuse practiced	Minimize metal disposal	widespread particularly in metal finishing
		Replace solvent cleaning	Aqueous cleaning	R&D underway	Eliminate VOCs or Freon/chloro-carbon solvent use	widespread - metal finishing painting, etc.

TABLE A-1 - INDUSTRIAL WASTE MINIMIZATION OPPORTUNITIES

INDUSTRY	SIC	PERCEIVED NEED	PROPOSED SOLUTIONS IF KNOWN	STATUS	POTENTIAL IMPACTS OF CHANGE	TRANSFER POTENTIAL
		Avoid need for solvent cleaning	Use of purer and other fluxes, etc.	Some R&D underway	Eliminate VOC's or halocarbons/freons	widespread
Auto Assembly	371	Paint VOC and metallic pigment control	New paint application processes	Implemented and being developed with paint manufacturers	Reduce/eliminate VOCs, metals	Significant but cost dependent - in industry primarily
			Other sources, such as plastic scrap, lubricant leaks from equipment, etc. are all seen as the same as found in other industries			
Laundries and Dry Cleaning	721	Still Bottoms Mgmt.	Improved solvent recovery by water addition in distillation	Assoc. has done R&D. Demonstration would aid implementation	Reduce hazardous waste volume disposed, VOC emissions	limited to larger plants with stills
		Filter Mgmt.	Improved removal of residual solvent	Some work done, new techniques include microwave heating. R&D underway, but limited	Reduce solvent losses and discharge of VOCs or halocarbons	potentially extensive

TABLE A-1 - INDUSTRIAL WASTE MINIMIZATION OPPORTUNITIES

INDUSTRY	SIC	PERCEIVED NEED	PROPOSED SOLUTIONS IF KNOWN	STATUS	POTENTIAL IMPACTS OF CHANGE	TRANSFER POTENTIAL
Auto Repair Refinishing	753	Solvent disposal small scale reuse	Redistillation, reuse	Stills available, use limited	Reduce solvent purchase and disposal	very extensive
		Spray painting VOC control	Small scale vapor recovery/reuse	No technology exists for small generations	Eliminate large VOC generation, decrease solvent purchase	extensive
		Non-solvent cleaning to eliminate solvents	Aqueous cleaning solutions and systems	limited availability	Eliminate solvents and VOC's (fugitives); water waste will need control	extensive
		Low VOC paints, painting	High solids coatings Electrostatic painting, water-based paints	Not currently available for refinishing industry	Eliminate VOC's	extensive
Generic	---	VOC control-process emissions; reuse of solvents	Smaller scale, lower cost adsorption, condensation, membrane systems	No work seems to be underway for small source control	Eliminate or recover significant quantities of VOCs	Extensive, e.g., chemical, auto repair, food, plastics, printing, etc.
		VOC control-fugitive emissions	Improved designs for valves, flanges, material transfer, etc.	No concerted effort, but changes are being made	Minimize fugitive VOCs	Extensive, particularly in process industries

TABLE A-3 - INDUSTRIAL WASTE MINIMIZATION OPPORTUNITIES

INDUSTRY	SIC	PERCEIVED NEED	PROPOSED SOLUTIONS IF KNOWN	STATUS	POTENTIAL IMPACTS OF CHANGE	TRANSFER POTENTIAL
		CFC Substitutes	Modified fluorocarbons	Major work by CFC manufacturers	Avoid ozone layer damage	Plastic foams
			Non-CFC refrigeration systems	RD&D underway no details	"	Widespread commercial, industrial residential uses
		Oil/Water separation	Improved designs, new emulsion-breaking approaches	Limited work seems to be underway particularly by oil product vendors	Minimize oil contamination of water discharges	Widespread industrial and POTW uses
		Improved seals, valves etc. (see VOCs/fugitive) Reduce material losses	Improved designs, more reliable products	No concerted work	Reduce VOC's and liquid product losses during operation and, particularly during start-up/shutdown	Process industries - particularly multiproduct industries
		Equipment update to optimize processes	Redesign, increased automation & computer control	No concerted effort; many systems are/would be one-of-a-kind	Reduce losses during start-up/shutdown; improve yields, reduce by-products, wastes	Widespread - e.g., process industries, printing, textile finishing
		Bath testing/process control to optimize processes	Increased automation, on-line monitoring, quality determinations	no concerted work	Increase recycle potential for baths, reduce discharge of "spent" reagents, rinses, etc.	Widespread

TABLE A-1 - INDUSTRIAL WASTE MINIMIZATION OPPORTUNITIES

INDUSTRY	SIC	PERCEIVED NEED	PROPOSED SOLUTIONS IF KNOWN	STATUS	POTENTIAL IMPACTS OF CHANGE	TRANSFER POTENTIAL
		Small scale recovery systems	Scale down and/or redesign and/or adsorption, condensation, membrane systems	no concerted work	Make solvent recovery, bath purification available to smaller firms	Widespread
		Raw material, product, waste tracking systems for small businesses	PC data base for the non-computer expert. Specific modules for specific industries	no concerted work	By providing small businesses with better info. on use (& cost) will motivate recycling, reuse, etc.	Widespread
		Degreasing-minimize solvent use	Improved vapor recovery; aqueous degreasing	limited work on aqueous systems; some problems	Reduce/eliminate VOCs, CFCs. Extend bath life. Introduces aqueous wastes requiring treatment/disposal	Widespread-auto, electronics, metal fabrication
		Acid recovery	Distillation or membrane processes	On-again, off-again R&D over the years. Allied now has membrane process	Decrease need for neutralization, disposal	Steel, non-ferrous, chemical

Table 2. Checklist for All Industries Source: USEPA; Facility Pollution Prevention Guide

Waste Origin/Type	Pollution Prevention and Recycling Methods
Material Receiving/ Packaging materials, off-spec materials, damaged container, inadvertent spills, transfer hose emptying	Use "Just-in-Time" ordering system. Establish a centralized purchasing program. Select quantity and package type to minimize packing waste. Order reagent chemicals in exact amounts. Encourage chemical suppliers to become responsible partners (e.g., accept outdated supplies). Establish an inventory control program to trace chemical from cradle to grave. Rotate chemical stock. Develop a running inventory of unused chemicals for other departments' use. Inspect material before accepting a shipment. Review material procurement specifications. Validate shelf-life expiration dates. Test effectiveness of outdated material. Eliminate shelf-life requirements for stable compounds. Conduct frequent inventory checks. Use computer-assisted plant inventory system. Conduct periodic materials tracking. Properly label all containers. Set up staffed control points to dispense chemicals and collect wastes. Buy pure feeds. Find less critical uses for off-spec material (that would otherwise be disposed). Change to reusable shipping containers. Switch to less hazardous raw material. Use rinsable/recyclable drums.
Raw Material and Product Storage/ Tank bottoms; off-spec and excess materials; spill residues; leaking pumps, valves, tanks, and pipes; damaged containers; empty containers	Establish Spill Prevention, Control, and Countermeasures (SPCC) plans. Use properly designed tanks and vessels only for their intended purposes. Install overflow alarms for all tanks and vessels. Maintain physical integrity of all tanks and vessels. Set up written procedures for all loading/unloading and transfer operations. Install secondary containment areas. Instruct operators to not bypass interlocks, alarms, or significantly alter setpoints without authorization. Isolate equipment or process lines that leak or are not in service. Use sealless pumps.

Table 2. (Continued)

Waste Origin/Type	Pollution Prevention and Recycling Methods
Raw Material and Product Storage/ (Continued)	Use bellows-seal valves. Document all spillage. Perform overall materials balances and estimate the quantity and dollar value of all losses. Use floating-roof tanks for VOC control. Use conservation vents on fixed roof tanks. Use vapor recovery systems. Store containers in such a way as to allow for visual inspection for corrosion and leaks. Stack containers in a way to minimize the chance of tipping, puncturing, or breaking. Prevent concrete "sweating" by raising the drum off storage pads. Maintain Material Safety Data Sheets to ensure correct handling of spills. Provide adequate lighting in the storage area. Maintain a clean, even surface in transportation areas. Keep aisles clear of obstruction. Maintain distance between incompatible chemicals. Maintain distance between different types of chemicals to prevent cross-contamination. Avoid stacking containers against process equipment. Follow manufacturers' suggestions on the storage and handling of all raw materials. Use proper insulation of electric circuitry and inspect regularly for corrosion and potential sparking. Use large containers for bulk storage whenever possible. Use containers with height-to-diameter ratio equal to one to minimize wetted area. Empty drums and containers thoroughly before cleaning or disposal. Reuse scrap paper for note pads; recycle paper.
Laboratories/ Reagents, off-spec chemicals, samples, empty sample and chemical containers	Use micro or semi-micro analytical techniques. Increase use of instrumentation. Reduce or eliminate the use of highly toxic chemicals in laboratory experiments. Reuse/recycle spent solvents. Recover metal from catalyst.

Table 2. (Continued)

Waste Origin/Type	Pollution Prevention and Recycling Methods
Laboratories (Continued)	Treat or destroy hazardous waste products as the last step in experiments. Keep individual hazardous waste streams segregated, segregate hazardous waste from nonhazardous waste, segregate recyclable waste from non-recyclable waste. Assure that the identity of all chemicals and wastes is clearly marked on all containers. Investigate mercury recovery and recycling.
Operation and Process Changes Solvents, cleaning agents, degreasing sludges, sandblasting waste, caustic, scrap metal, oils, greases from equipment cleaning	Maximize dedication of process equipment. Use squeegees to recover residual fluid on product prior to rinsing. Use closed storage and transfer systems. Provide sufficient drain time for liquids. Line equipment to reduce fluid holdup. Use cleaning system that avoid or minimize solvents and clean only when needed. Use countercurrent rinsing. Use clean-in-place systems. Clean equipment immediately after use. Reuse cleanup solvent. Reprocess cleanup solvent into useful products. Segregate wastes by solvent type. Standardize solvent usage. Reclaim solvent by distillation. Schedule production to lower cleaning frequency. Use mechanical wipers on mixing tanks.
Operation and Process Changes Sludge and spent acid from heat exchanger cleaning	Use bypass control or pumped recycle to maintain turbulence during turndown. Use smooth heat exchange surfaces. Use on-stream cleaning techniques. Use high pressure water cleaning to replace chemical cleaning where possible. Use lower pressure steam.

Table 3. Checklist for the Printing Industry

Waste Origin/Type	Pollution Prevention and Recycling Method
Image Processing/Empty containers, used film packages, outdated material	Recycle empty containers. Recycle spoiled photographic film.
Image Processing/ Photographic chemicals, silver	Use silver-free films, such as vesicular, diazo, or electrostatic types.. Use water-developed litho plates. Extend bath life. Use squeegees to reduce carryover. Employ countercurrent washing. Recover silver and recycle chemicals.
Plate Making/Damaged plates, developed film, outdated materials	Use electronic imaging, laser plate making.
Plate Making/ Acids, alkali, solvents, plate coatings (may contain dyes, photopolymers, binders, resins, pigment, organic acids), developers (may contain isopropanol, gum arabic, lacquers, caustics), and rinse water	Electronic imaging/laser print making. Recover silver and recycle chemicals. Use floating lids on bleach and developer tanks. Use countercurrent washing sequence. Use squeegees to reduce carryover. Substitute iron-EDTA for ferrocyanide. Use washless processing systems. Use better operating practices. Remove heavy metals from wastewater.
Finishing/Damaged products, scrap	Reduce paper use and recycle waste paper.
Printing/ Lubricating oils, waste ink, cleanup solvent (halogenated and nonhalogenated), rags	Prepare only the quantity of ink needed for a press run. Recycle waste ink and solvent. Schedule runs to reduce color change over. Use automatic cleaning equipment. Use automatic ink leveler. Use alternative solvents. Use water-based ink. Use UV-curable ink. Install web break detectors. Use automatic web splicers. Store ink properly. Standardize ink sequence. Recycle waste ink.

Table 4. Checklist for the Fabricated Metal Industry

Waste Origin/Type	Pollution Prevention and Recycling Methods
Machining Wastes/ Metalworking Fluid	Use of high-quality metalworking fluid. Use demineralized water makeup. Perform regularly scheduled sump and machine cleaning. Perform regularly scheduled gasket, wiper, and seal maintenance. Filter, pasteurize, and treat metalworking fluid for reuse. Assigning fluid control responsibility to one person. Standardize oil types used on machining equipment. Improve equipment scheduling/establish dedicated lines. Reuse or recycle cutting, cooling, and lubricating oils. Substitute insoluble borates for soluble borate lubricants.
Machining Wastes/ Metal wastes, dust, and sludge	Segregate and reuse scrap metal.
Parts Cleaning/ Solvents	Install lids/silhouettes on tanks. Increase freeboard space on tanks. Install freeboard chillers on tanks. Remove sludge from solvent tanks frequently. Extend solvent life by precleaning parts by wiping, using air blowers, or predipping in cold mineral spirits dip. Reclaim/recover solvent on- or off-site. Substitute less hazardous solvent degreasers (e.g., petroleum solvents instead of chlorinated solvents) or alkali washes where possible. Distribute parts on rack to allow good cleaning and minimize solvent holup. Slow speed of parts removal from vapor zone. Rotate parts to allow condensed solvent drop-off.
Parts Cleaning/ Aqueous Cleaners	Remove sludge frequently. Use dry cleaning and stripping methods. Use oil separation and filtration to recycle solution.
Parts Cleaning/ Abrasives	Use of greaseless or water-based binders. Use an automatic liquid spray system for application of abrasive onto wheel. Ensure sufficient water use during cleaning by using water level control. Use synthetic abrasives.
Parts Cleaning/ Rinsewater	Improve rack and barrel system design. Use spray, fog, or chemical rinses. Use deionized water makeup to increase solution life.

Table 5. Checklist for the Metal Casting Industry

Waste Origin/Type	Pollution Prevention and Recycling Methods
Baghouse Dust and Scrubber Waste/ Dust contaminated with lead, zinc, and cadmium	Identify the source of contaminants, e.g., coatings on scrap, and work with suppliers to find raw materials that reduce the contaminant input. Install induction furnaces to reduce dust production. Recycle dust to original process or to another process. Recover contaminants with pyrometallurgical treatment, rotary kiln, hydrogen reduction, or other processes. Recycle to cement manufacturer.
Production of Ductile Iron/ Hazardous slag	Reduce the amount of sulfur in the feedstock. Use calcium oxide or calcium fluoride to replace calcium carbide as the desulfurization agent. Improve process control. Recycle calcium carbide slag.
Casting/ Spent casting sand	Material substitution, e.g., olivine sand is more difficult to detoxify than silica sand. Separate sand and shot blast dust. Improve metal recovery from sand. Recover sand and mix old and new sand for mold making. Recover sand by washing, air scrubbing, or thermal treatment. Reuse sand for construction if possible.

Table 6. Checklist for the Printed Circuit Board Industry

Waste Origin/Type	Pollution Prevention and Recycling Methods
PC Board Manufacture/ General	Product substitution: Surface mount technology Injection molded substrate and additive plating
Cleaning and Surface Preparation/ Solvents	Materials substitution: Use abrasives Use nonchelated cleaners Increase efficiency of process: Extend bath life, improve rinse efficiency, countercurrent cleaning Recycle/reuse: Recycle/reuse cleaners and rinses
Pattern Printing and Masking/ Acid fumes/organic vapors; vinyl polymers spent resist removal solution; spent acid solution; waste rinse water	Reduce hazardous nature of process: Aqueous processable resist Screen printing versus photolithography Dry photoresist removal Recycle/reuse: Recycle/reuse photoresist stripper
Electroplating and Electroless Plating/ Plating solutions and rinse wastes	Eliminate process: Mechanical board production Materials substitution: Noncyanide baths Noncyanide stress relievers Extend bath life; reduce drag-in: Proper rack design/maintenance, better precleaning/rinsing, use of demineralized water as makeup, proper storage methods Extend bath life; reduce drag-out: Minimize bath chemical concentration, increase bath temperature, use wetting agents, proper positioning on rack, slow withdrawal and sample drainage, computerized/automated systems, recover drag-out, use airstreams or fog to rinse plating solution into the tank, collect drips with drain boards. Extend bath life; maintain bath solution quality: Monitor solution activity Control temperature Mechanical agitation Continuous filtration/carbon treatment Impurity removal Improve rinse efficiency: Closed-circuit rinses Spray rinses Fog nozzles

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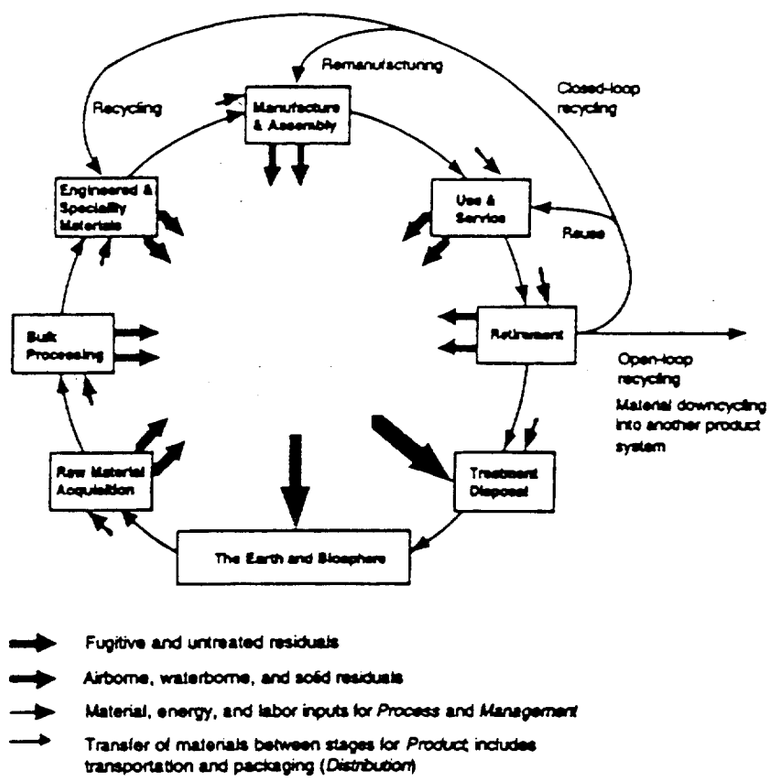
Table 6. (Continued)

Waste Origin/Type	Pollution Prevention and Recycling Methods
Electroplating and Electroless Plating/ (Continued)	Improve rinse efficiency (continued): Increased agitation Countercurrent rinsing Proper equipment design/operation Deionized water use. Turn off rinsewater when not in use. Recovery/reuse: Segregate streams Recover metal values.
Etching/ Etching solutions and rinse wastes	Eliminate process: Differential plating Use dry plasma etching. Materials substitution: Nonchelated etchants Nonchrome etchants. Increased efficiency: Use thinner copper cladding Pattern vs. panel plating Additive vs. subtractive method. Reuse/recycle: Reuse/recycle etchants.

Table 7. Checklist for the Coating Industry

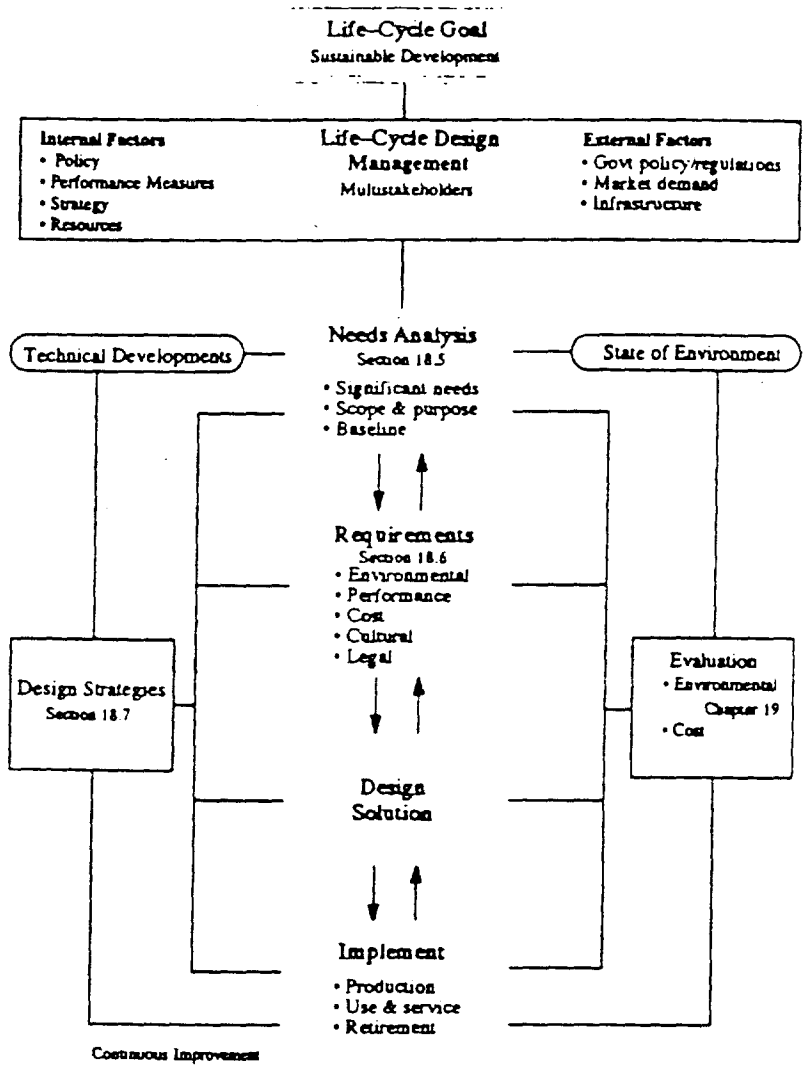
Waste Origin/Type	Pollution Prevention and Recycling Methods
Coating Overspray/ Coating material that fails to reach the object being coated	Maintain 50% overlap between spray pattern. Maintain 6- to 8-inch distance between spray gun and the workpiece. Maintain a gun speed of about 250 feet/minute. Hold gun perpendicular to the surface. Trigger gun at the beginning and end of each pass. Properly train operators. Use robots for spraying. Avoid excessive air pressure for coating atomization. Recycle overspray. Use electrostatic spray systems. Use turbine disk or bell or air-assisted airless spray guns in place of air-spray guns. Install on-site paint mixers to control material usage. Inspect parts before coating.
Stripping Wastes/ Coating removal from parts before applying a new coat	Avoid adding excess stripper. Use spent stripper as rough prestrip on next item. Use abrasive media paint stripping. Use plastic media bead-blasting paint stripping. Use cryogenic paint stripping. Use thermal paint stripping. Use wheat starch media blasting paint stripping. Use laser or flashlamp paint stripping.
Solvent Emissions/ Evaporative losses from process equipment and coated parts	Keep solvent soak tanks away from heat sources. Use high-solids coating formulations. Use powder coatings. Use water-based coating formulations. Use UV cured coating formulations.
Equipment Cleanup Wastes/ Process equipment cleaning with solvents	Use light-to-dark batch sequencing. Produce large batches of similarly coated objects instead of small batches of differently coated items. Isolate solvent-based paint spray booths from water-based paint spray booths. Reuse cleaning solution/solvent. Standardize solvent usage. Clean coating equipment after each use.
Source Reduction	Reexamine the need for coating, as well as available alternatives. Use longer lasting plastic coatings instead of paint.

PRODUCT LIFE CYCLE SYSTEM



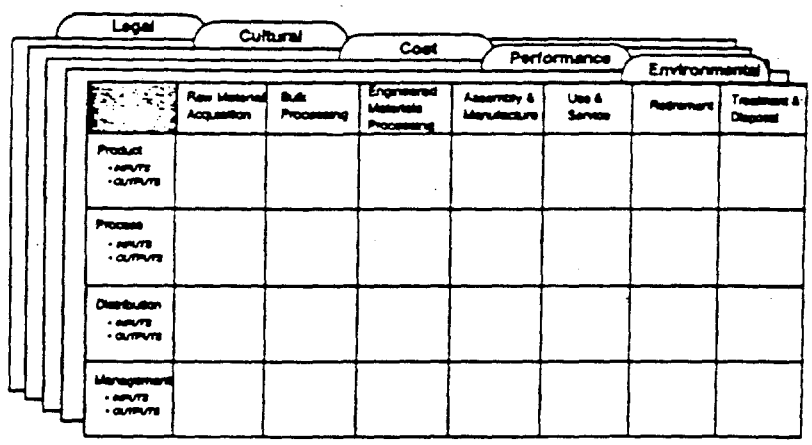
Source: Freeman, Harry; Industrial Pollution Prevention Handbook

PRODUCT DEVELOPMENT FLOWCHART



Source: Freeman, Harry; Industrial Pollution Prevention Handbook

REQUIREMENT MATRIX



Source: Freeman, Harry; Industrial Pollution Prevention Handbook

Environmental Matrix

Product
Material type—Based on a materials inventory of components/parts (refrigerator/freezer compartments, refrigeration system, compressor, condenser, evaporator, fans, electric components). Eliminate high-impact materials: substitute for CFC-12 with lower ozone-depleting-potential and global-warming-potential alternatives. Material amount Reduce material intensiveness: specify pounds of material. Residuals—Specified in Retirement stage.
Process
Energy Reduce energy use: specify energy consumption for compressor, fans, antisweat heaters (average yearly energy use). People Noise: specify frequency and maximum loudness. Residuals Reduce waste: specify systems for recovering refrigerant during service; specify level of refrigerant loss during normal use and service; requirements for reuse, remanufacture, recycle of components are stated in Retirement stage.
Distribution
Material type Reduce impacts associated with packaging materials: specify low-impact materials. Material amount Reduce material intensiveness of packaging: specify pounds of material. Energy Conserve transportation energy: specify constraints on energy associated with delivery. Residuals Reduce packaging waste: specify reusable, recyclable packaging. Reduce product waste: specify maximum amount of damaged products during distribution.
Management
Information Provide consumers with information on energy use: meet DOE labeling requirements for energy efficiency.

Cultural Matrix

Product
Material Color preferences. Size (dependent on frequency of shopping and on convenience). Finishes and materials (affects cleaning, appearance).
Process
Material Manual vs. automatic defrost: Compartmentalization—ability to organize food. Residuals Food spoilage—ability to control temperature.
Management
Information Instructions clearly written.

Source: Freeman, Harry; Industrial Pollution Prevention Handbook

Cost Matrix

Product
Material Retail price. Cost for replacement parts.
Process
Material and labor Service costs (cost for service and parts).
Energy Electricity ($/kWh × kWh/yr).
Distribution
Material, energy, and labor Delivery and installation cost.
Residuals Packaging disposal cost.
Management
Information Manufacturer's guarantee. Payback period to user for purchasing more expensive energy-efficient unit.

Performance Matrix

Product
Material Dimensions: H × W × D; capacity in cubic feet; shelf area; usable storage space. Features: ice making; meat keeping; crisper humidity.
Process
Material Identify best available technology for refrigeration system components as a practical limit to performance. Specify useful life of product and components Specify reliability. Specify durability.
Energy Identify thermodynamic limits to performance (e.g., maximum efficiency determined by temperatures inside and outside the refrigerator). Specify temperature control: balance, uniformity, compensation.
Distribution
Material Specify product demand. Specify installation time and equipment requirements. Specify packaging requirements for protection and containment.
Energy Specify location of retail outlets relative to market.
Management
ıer's manual.

Source: Freeman, Harry; Industrial Pollution Prevention Handbook

Legal Matrix

Product
Material Consumer Product Safety Commission. Montreal Protocol for discontinuing the use of CFCs. TSCA (Refrigerants meet regulations for use).
Process
Energy National Appliance Energy Conservation Act—January 1, 1993 [maximum energy consumption rate = E = 16.0 AV + 355 kWh/yr (AV = adjusted volume of top-mounted refrigerator)].
Distribution
Residuals Packaging: German take-back legislation; community recycling ordinance.
Management
Information FTC guidelines on environmental claims. DOE labeling requirements for energy efficiency.

Source: Freeman, Harry; Industrial Pollution Prevention Handbook

Design Strategies

General strategy	Specific strategy
Product life extension	Appropriately durable Adaptable Reliable Serviceable Remanufacturable Reusable
Material life extension	Recycling
Material selection	Reformulation Substitution
Reduced material intensiveness	
Process improvement (see Chaps. 21–26)	Process substitution Process control Improved process layout Inventory control and material handling Facility planning (Chap. 12)
Efficient distribution	Transportation Packaging
Improved management practices	Office management (Chap. 30) Total quality management (Chap. 9) Accounting (Chap. 16)
Improved information provision	Product labeling (Chap. 20)

Source: Freeman, Harry; Industrial Pollution Prevention Handbook

POLLUTION PREVENTION TIPS

SOLVENT LOSS CONTROL-
THINGS YOU CAN DO NOW

Background:

Chlorinated solvent users are facing greater regulation and cost in the use of these products in cleaning applications. Public concern over ozone depletion and "greenhouse" gases, shrinking alternatives to and cost of residuals disposal and accelerating raw material costs have all users looking for alternatives.

Defense suppliers must meet military specification cleaning requirements which often limit use of less costly alternatives. Many larger industries adopt military specifications as their own standards for simplicity. Until changed and alternative cleaning processes have been approved, many suppliers must still use chlorinated and halongenated solvents.

Solvents either under regulatory control now or have been identified for future controls include:

Solvent	Property
Methylene Chloride	Toxic, suspected carcinogen
Perchloroethylene	Toxic, suspected carcinogen
Trichloroethylene (TCE(	VOC - photochemical reactor
1,1,1, Trichloroethane (TCA)	Stratospheric ozone depleter
Trichlorotrifluoroethane (CFC 113)	Stratospheric ozone depleter

In use, losses occur mainly from fugitive releases in the work place, disposal of still bottoms and cleaning residue from tanks. Losses can be reduced by taking several simple and relatively inexpensive steps. Pending approval of less costly and environmentally sound cleaning alternatives, an audit of your operating practices and processes could identify areas to reduce consumption, reduce generation of waste, and save money. This report identifies where losses occur, outlines reduction techniques and presents one company's results achieved through conservation actions on open top and in-line cleaners.

Alcatel, a Raleigh, North Carolina electronics manufacturing company, has achieved measurable results by implementing many of these recommendations. A summary of the company's actions is included in this report.

OPEN TOP CLEANERS

With open top vapor cleaners (OTVC), losses occur both when in or out of operation. During idling or downtime, losses occur at the solvent vapor and air interface. Evaporation from cold solvents and convection currents from warm freeboards move (diffuse) solvent vapor into ambient air around the cleaner. Losses can also occur at any solvent feed line connector, pump seals or any other physical linkage in the system.

Losses from OTVC while in operation are greatest during workload entry into and exit from the cleaning tank vapor zone. Air and solvent are displaced by the basket or part as it is lowered into the the tank. The vapor zone also contracts and expands as the hot vapor condenses on and heats parts being cleaned. This pumping effect and movement of the vapor zone increases mixing in the air above the vapor zone and subsequent exhaust out of the cleaner. These losses can be reduced by simple operational changes and minor equipment modification.

Air flow around open areas increases solvent loss. Exhaust collection systems over open top cleaners capture air laden solvents to reduce work place concentrations but often contribute to greater solvent losses by creating positive air flows away from the vapor zone. Processing air captured in the exhaust system through carbon absorbers and cycling back into the solvent zone helps but does not eliminate losses. Some control options are listed in Table I.

IN-LINE CLEANERS

In-line cleaners will have solvent losses similar to open top cleaners but paths to the environment differ. Solvent drag out from in-line cleaners is a major source of solvent loss. Since the solvent surface is not as open to the air during idling times, diffusion into the air around the machine will not be as great.

Some losses are similar in both open top and in-line cleaners. The rate at which a part is moved through the vapor zone has a large influence on the amount of vapor or solvent pushed or pulled from the cleaner - whether open top or in-line. In general, the slower the movement, the less solvent is lost. Solvent filling and draining with both types of cleaners provide additional opportunities for conservation. Filling from buckets will cause greater loss than from a closed circuit system.

Solvent loss source remedial actions, process modifications and possible equipment changes are listed in Table II.

TABLE I - SOLVENT LOSS CONTROL OPEN TOP CLEANERS

SOURCE OF LOSS	ALTERNATIVE CONTROLS	OTHER CONSIDERAT
Evaporation, convection, diffusion, out top.	Increase freeboard to width ratio to at least 1.0.	Place unit where air currents across top are minimized. (Away from windows, fans, vents, etc.). Defle air currents away fr open tops.
	Install freeboard refrigeration coils (operates at -20° F.).	Plan for increased c densate water dispos
	Reduce primary condenser temperature.	
	Install automated cover.	Top should be kept closed during idle or downtimes. Keep condenser coils on during downtime.
	Capture escaping solvent with exhaust system. (CAUTION: VACUUM HEAD CAN ACCELERATE EVAPORATIVE LOSSES)	Add carbon absorber and recycle captured solvents (may not be as effective as free- board refrigerati
Drag out/vapor zone disturbance	Reduce part/work unit movement in and out of vapor zone to minimum speed consistent with production needs. If automated do not exceed 11 feet/min.	Orient part for best drainage. Keep work load in vapor zone until condensation stops. Keep workloac within freeboard until dry. Remove slowly. If rinse within same tank, drain parts over solvent sump.
Vapor Zone disturbance	Reduce basket or work size to utilize 50% or less of opening.	Lower work into and remove from vapor zon at slow steady rate.
Mechanical Leak, other losses	Check joints, connectors and seals in solvent system with halon detector. Stop all leaks. Use specified gaskets and materials.	Scale often forms around leaks for visual detection. Leak checks should be routine maintenance activity.
	Install downtime cover.	Insure good fit aroun edges.

TABLE II - LOSS CONTROL - IN-LINE CLEANERS

SOURCE OF LOSS	ALTERNATIVE CONTROLS	OTHER CONSIDERATIONS
Solvent losses to ambient air	Freeboard to width ratio should be at least 1.0.	
	Install freeboard refrigeration system (for vapor cleaners only)	Plan for increased cc densate water dispose
	Minimize air flow around unit. Keep entrance and exit openings closed during down time.	Consider adding extension to exit to extend drying time. Install flaps over op ings for use during down time.
Mechanical	Check all connections, top leaks, and set up continuous maintenance program.	
	Transfer solvent through closed piping loop system.	Install carbon absorb tion unit in loop to capture and recycle solvent.
	Check top edges for leaks. Recaulk as necessary.	Glass tops should be checked for cracks. Replace if leaking.
	Reduce entrance and exit openings.	Opening should have l than 10% free width during part passage.
Operational	Reduce conveyor speed to minimum consistent with production needs.	Do not exceed 11 fpm.
	Keep work load in vapor zone until condensation stops.	Allow to dry within cleaner if possible. Orient parts for optimum drainage.
	Install sump cooling system and activate during downtime.	Spray rinse at a down ward angle into solve Spray nozzle should b as far into freeboard as work will permit.

ALCATEL

Alcatel manufactures circuit boards for their own telephone switching systems. The Raleigh operations consumed some 86,000 pounds of CFC's during 1987. Manufacturing cleaning operations incorporate both in-line and open top vapor cleaners.

In June, 1989, Alcatel manufacturing engineering personnel initiated in process changes to reduce Freon consumption. An old Detrex in-line cleaner was replaced with a $90,000 new design Detrex cleaner which has added cooling coils at the entrance to and exit from the cleaner. Internal modifications, designed to reduce solvent loss from the cleaning zone, have been added. Daily CFC usage has dropped from 13 gallons to 4 gallons per day from this one operation. This amounts to a 70% consumptive reduction. Based on a five day, 40 hour week production schedule, the unit will pay for itself in less than 16 months at today's Freon prices. If present 15% quarterly price increases continue or accelerate as expected, the pay back period could be less than 12 months.

Additionally, open top cleaner losses have been reduced from 8 gallons per day to 5 gallons per day. This was accomplished through improved maintenance, stopping leaks, keeping cooling coils on and covered during idling and down time and redirecting air flows away from cleaners. Additionally, Alcatel installed an automated hoist on one open top cleaner to regulate entry and exit speeds of parts thus reducing drag out. On an annual basis the combined solvent consumption from open top and in-line cleaners would be reduced 57%. Conservation actions are on-going. Additional operational practice changes are being implemented to reduce losses due to drag out from open tank cleaners.

Alcatel's total consumption of Freon, 86,000 pounds in 1987, 74,000 pounds in 1988 (business slow down), will be reduced to 46,000 pounds in 1989 mainly as a result of the purchase of new equipment. A 1990 goal of 31,000 pounds has been established with all solvent usage to be eliminated by 1993. The company is moving aggressively to meet these goals.

For additional information contact:

Office of Waste Reduction
Pollution Prevention Program
N.C. Department of Environment, Health & Natural Resources
Post Office Box 27687
Raleigh, NC 27611-7687

Telephone: (919) 571-4100

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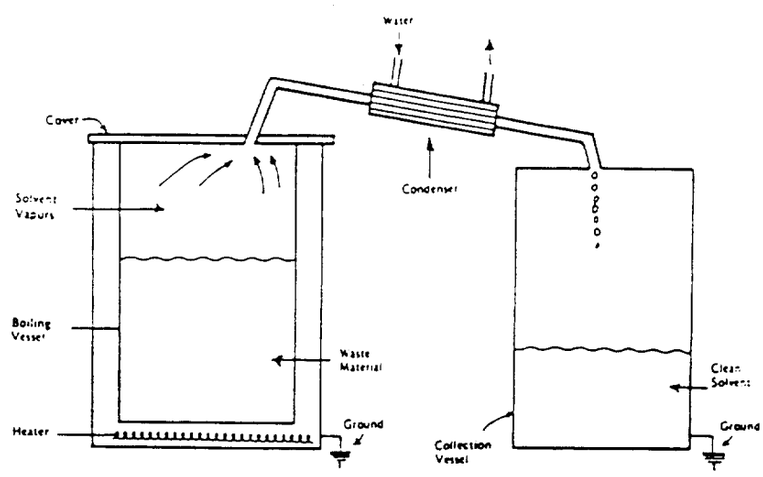
SMALL SOLVENT RECOVERY SYSTEMS

Many North Carolina firms are saving thousands of dollars each year in raw material and waste disposal costs by recovering and reusing waste solvents. Widely available batch solvent recovery systems can cost-effectively recover solvents contained in waste material. The recovered solvents can then be reused in the production process. This will reduce operating costs by reducing the quantity of raw material needed in the process as well as the volume of waste which has to be managed. Many recovery systems can pay for themselves in as little as a year or less. Types of available batch distillation systems, operating costs, and cost savings are discussed in the following sections.

Batch Solvent Recovery Systems

A basic batch distillation system consists of a boiling chamber, heat source, condenser, and a clean solvent collection container, as shown below:



Batch Distillation System

The units operate by first pumping or pouring spent solvent into the boiling chamber. The top is then sealed and the unit started. After approximately 1 to 1 1/2 hours, clean solvent will start flowing into the collection drum. About 6 hours later the solvent will stop flowing and the recovery process will be complete. The unit is then turned off and allowed to cool. The top is then removed and the residue (distillation bottoms) is removed from the boiling chamber. The system is now ready to process the next batch of waste material. One batch of waste material can thus be processed about every 8 hours.

Batch distillation systems can recover most common solvents either under atmospheric or vacuum distillation. This includes methylene chloride, 1,1,1 trichloroethane, acetone, mineral spirits, xylene, methyl ethyl ketone, and toluene. Solvents can be recovered from a wide variety of waste materials including paints, lacquers, wash-off solvents, inks, cleaning solvents, degreasing solvents, and adhesives. The recovered material, depending on its composition, can be reused in the production process as make-up or as cleaning solvent. The residue left in the distillation system after the solvent is recovered in most cases is a hazardous waste. Unless the distillation bottoms can be reused they must be manifested and sent to a permitted hazardous waste management facility. Check with the Solid and Hazardous Waste Management Branch about management options for this material. They can be contacted at 919-733-2178.

Solvent wastes should be kept segregated by their common constituents or characteristics during the collection process. This will improve the recovery efficiency of the process as batch distillation systems cannot readily fractionate mixed solvents. All materials with a boiling point below the unit's set operating temperature will be recovered. Those with a higher boiling point will be left in the distillations bottoms. Depending on the physical and chemical characteristics of the solvent mixture, batch systems may be able to separate individual solvents if there is a significant difference in their boiling points. To recover compounds with high boiling points (up to 500°F) or heat-sensitive compounds, a vacuum unit can be used to lower the boiling chamber operating temperature. This will reduce the solvents boiling temperature and increase the unit's ability to recover high boiling point compounds.

Commercial units are available in a range of sizes; the smallest can handle 5 gallons of waste material per batch. These systems are usually electrically heated and, depending upon the unit's size, power requirements range from about 1/2 to 6 kilowatts. A water- or air-cooled condenser is used to cool the solvent vapors. A water-cooled condenser will use from 1/4 GPM to 2 GPM depending on the size of the system. Some units also require compressed air to operate the boiling chamber cover.

The distillation system must meet all applicable fire and electrical codes and be of explosion-proof design if flammable solvents are recovered. Additionally, the units must be installed and located in accordance with all local building codes. This can include installing explosion-proof electrical systems and placing it in a location which meets certain building standards for explosion hazards.

Before a system is selected and installed, the waste solvent must be analyzed to determine if it can be recovered and the applicable operating parameters. This testing is usually done by equipment vendors and may include a chemical analysis and/or a small test run on a model unit. A list of equipment suppliers can be obtained from the Pollution Prevention Pays Program.

Capital and Operating Costs

The capital cost of a batch distillation system will depend on the equipment's manufacturer, the unit's capacity, and its operating features. For example, the cost of stills produced by one firm range from about $3,000 for a 5-gallon capacity system to $15,000 for a 55-gallon system. These are modular systems and only require water, electricity and, in some cases, compressed air before they are fully operational. Example installation costs are as follows:

- o Electrical: materials and installation costs for 50 feet of wire, conduit and explosion-proof fittings will cost about $300.

- o Water: materials and installation cost for 50 feet of piping, valves, and necessary fittings will be about $200.

Operating costs will vary with the size of the unit and will consist of utility costs, labor, and, in some cases, disposable boiling vessel liners. The breakdown of the typical costs for a 55-gallon capacity system are as follows:

o Labor (1 hr/shift)	$20.00 per batch
o Electricity	4.00 per batch
o Water	1.50 per batch
	Total $25.50 per batch

To this value must be added the cost of disposing of the residue generated during the recovery process. Costs will vary depending on the disposal option chosen, but off-site incineration can cost at least $3.00 per gallon for distillation bottoms containing non-chlorinated solvents. The cost of incinerating the bottoms from the recovery of chlorinated solvents will be higher. For the example system, this can add about $10-15 to the cost of each batch of non-chlorinated solvents recovered.

Cost Savings

On-site batch distillation systems can pay for themselves through reduced raw material costs, waste disposal costs, and liability. With the cost of recovering and reusing a solvent as low as $0.70 per gallon, the savings in virgin solvents costs alone can pay for the system. Add to this the reduced quantity, up to 90%, of hazardous waste which has to be managed and disposed of. Typically, payback periods range from 1 to 2 years, but can be as short as a few months. The actual period will depend on the value of the recovered solvent, the quantity of solvent in the waste material and the current method used to manage the waste solvent and the cost of managing the distillation bottoms..

A furniture plant in Mt. Olive paid for their distillation system in one year through reduced solvent purchases. The company uses a 15-gallon capacity system to recover spent lacquer thinner from the plant's wash-off operation. Because the composition of the solvent changes with distillation, the reclaimed solvent cannot be reused in the wash-off operation. Acetone is added to the reclaimed solvent and this reconstituted mixture is used for thinning coatings in the plant's spray

operation. The total cost of the reconstituted mixture is $1.67, while virgin solvent for the spray mix would cost $2.67. The company estimates that the savings in material and waste disposal costs is $5,700 a year.

On-site solvent recycling allowed a Lenoir-based firm to recover 95% of the xylene they used to clean their coating equipment and supply tanks. This saved the company more than $3,500 per year in virgin solvent and disposal costs, which paid for the recovery system in just 13 months. Additionally, it reduced the amount of waste material they had to store, reduced the amount of virgin material in inventory and allowed for added room for paint storage.

Additional Information

For additional information on solvent management contact:

Pollution Prevention Program
Office of Waste Reduction
N.C. Dept. of Environment, Health, and Natural Resources
Post Office Box 27687
Raleigh, NC 27611-7687

Telephone: 919-571-4100

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The typical total cost of purchasing and installing a two stage counter-current rinse system is about $1,800. A three stage system would be about $2,300.

page 4

There are no direct operational costs associated with these techniques. Though, they should be included in the facility's routine inspection and maintenance program.

The typical total cost of purchasing and installing a two stage counter-current rinse system is about $1,800. A three stage system would be about $2,300.

Pay Back

There are no direct operational costs associated with these techniques. Though, they should be included in the facility's routine inspection and maintenance program.

The pay back period for installing a counter-current rinse tank will depend on the quantity of water saved and the raw water costs. For example, if a two stage system is used to reduce the water flow from 6 gpm to 0.6 gpm, and the water and sewer charges are $2/1,000 gallons, the pay back period will be about 70 weeks. After this initial pay back period the system will reduce operating costs by about $1,350 per year, through water savings.

Pay Back

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In addition to these direct cost savings, a water conservation program can reduce the capital cost of any required end-of-pipe wastewater treatment system. A rough "rule of thumb" is that a precipitation system costs about $2,000 per gallon of flow per minute. Thus a substantial reduction in water flow can produce corresponding savings in treatment system costs. However, small or token reductions will yield very little, if any, savings.

In addition to these direct cost savings, a water conservation program can reduce the capital cost of any required end-of-pipe wastewater treatment system. A rough "rule of thumb" is that a precipitation system costs about $2,000 per gallon of flow per minute. Thus a substantial reduction in water flow can produce corresponding savings in treatment system costs. However, small or token reductions will yield very little, if any, savings.

Selected References

1. Kushner, J. B. and A. S. Kushner. Water and Waste Control For the Plating Shop. Second Edition. Gardner Publications. Cincinnati, Ohio. 1981.

2. Mohler, J. B. "The Art and Science of Rinsing". American Electroplating Society. Winter Park, Florida. 1973.

Selected References

1. Kushner, J. B. and A. S. Kushner. Water and Waste Control For the Plating Shop. Second Edition. Gardner Publications. Cincinnati, Ohio. 1981.

2. Mohler, J. B. "The Art and Science of Rinsing". American Electroplating Society. Winter Park, Florida. 1973.

3. Mohler, J. B. "Water Rinsing". In: Metal Finishing Guidebook and Directory Issue: '82. Metal Finishing. Hackenrack, New Jersey. 1982. pages 498-510.

Additional Information

For additional information on water conservation in the electroplating industry or other pollution prevention techniques, contact:

Pollution Prevention Program
NC Department of Environment, Health, & Natural Resources
P.O. Box 27687
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NC Department of Environment, Health, & Natural Resources

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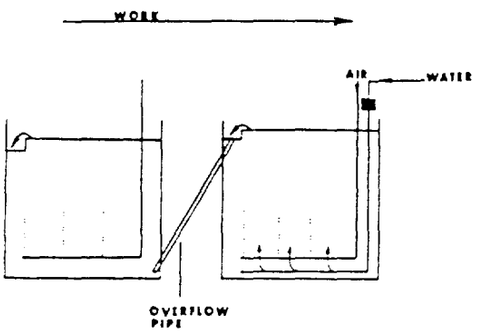
the May, 1982 issue of Plating and Surface Finishing) can be used. Such a system is shown below:



Gravity Feed System

Counter-current rinsing is not without its draw backs. One problem is the high cost of purchasing the systems. Another is that space limits the use of this technique as extra floor space is needed for the additional rinse tanks.

Capital and Operating Costs

The cost of a new 600 gallon two stage counter-current rinse system is about $1,300 while a 900 gallon three stage system is about $1,800. Installation costs, while very site specific, are estimated to be about $500. If extra tanks are available on-site then the cost of constructing a rinse system will be significantly less. For example, a gravity fed system using two separate tanks can cost as little as $120 to make. The costs includes $60 for an aerator, $10 for a mechanical flow control valve and $50 for 1" PVC pipe and necessary connectors for the overflow. The actual cost may be significantly higher depending on the modifications made to the rinse tanks.

Counter-current rinsing uses significantly less water than a single flowing rinse. Typically, two counter-current rinse tanks can reduce water use by 90 to 97%. The addition of a third tank will reduce water use by 95 to 99%. A fourth rinse tank will further reduce water use, however the additional small quantity of water saved may make it uneconomical.

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To illustrate the water saving from using counter-current rinsing let us examine a typical plating operation using a Watts nickel bath. Assume the bath solution contains 270,000 mg/l total dissolved solids. A single rinse tank would need about 110,250 gallons of fresh feed water for each gallon of plating solution dragged into the rinse tank. A two stage counter-current rinse tank would need only 82 gallons of water for each gallon of drag-out solution. While a single stage rinse tank system would need only 18 gallons of fresh water feed. As in all properly designed rinse tank systems agitation and flow control valves are used. Such an existing tank illustrated in the previous figure. These systems can be purchased new and ready to install or are existing rinse tank can be modified from one of the approaches below.

Another approach is to place a second and third rinse tank into the process line and gravity feed the rinse water from the last rinse tank to the first. Only a few inches of head is needed to gravity feed the water. If it is not possible to provide the required head then pumps can be used to circulate the water. Either small submersible pumps or a simple air lift pump (as described in

POLLUTION PREVENTION TIPS

POLLUTION PREVENTION TIPS

WATER CONSERVATION FOR ELECTROPLATERS: COUNTER-CURRENT RINSING

Counter-Current Rinsing Operation

In counter-current rinsing, the rinse water is circulated through a series of rinse tanks. Fresh water is fed into the rinse tank farthest from the process tank and overflows, inturn, to the rinse tank closest to the process tank. The work piece then, is dipped in the least pure water first and the cleanest water last. An example of a three stage counter-current rinse system is shown below:

WATER CONSERVATION FOR ELECTROPLATERS: COUNTER-CURRENT RINSING

Counter-Current Rinsing Operation

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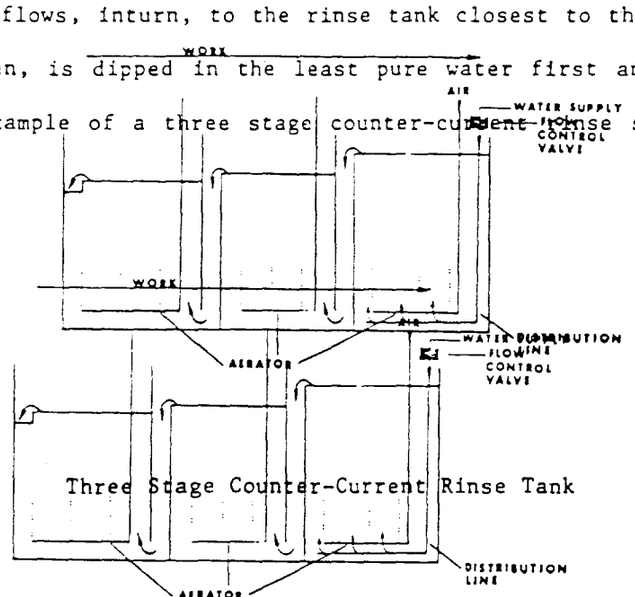


Three Stage Counter-Current Rinse Tank

Three Stage Counter-Current Rinse Tank

POLLUTION PREVENTION PROGRAM

NORTH CAROLINA DEPARTMENT OF ENVIRONMENT, HEALTH, AND NATURAL RESOURCES

POLLUTION PREVENTION TIPS

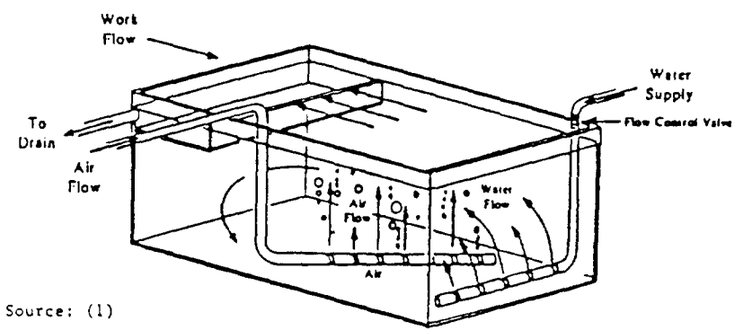
WATER CONSERVATION FOR ELECTROPLATERS: RINSE TANK DESIGN

Are your pouring money down the drain? You are if your firm does not have a water conservation program. Water is expensive to buy, treat, and dispose of. A water conservation program can cut water consumption by up to 50%, or even more, and the cost savings can pay for the required materials in a very short period of time. With average water and sewage rates about $2/1000 gallons, reducing the flow to a rinse tank by just 1 gpm can save $250 per year. Multiply this by the 20 or more rinse tanks in an average shop and it can add up to thousands of dollars per year in savings. Add to this the reduced capital costs of a waste treatment system and the savings can be even greater.

There are numerous methods which have been developed to conserve water in electroplating shops. Three of the major techniques, rinse tank design, counter current rinsing and rinse water reuse are the subjects of this series.

Rinse Tank Design

Proper rinse tank design is the cornerstone of any water conservation program. The most important factor in rinse tank design is to ensure that the rinse water is completely mixed. This will eliminate short circuiting of the feed water and effectively use all of the tank's volume. As shown below, a rinse tank must include a feed water distribution line, air agitation, and a flow control valve.



Source: (1)

Proper Rinse Tank Design

A water distribution line placed on the bottom of the far end of the tank will evenly distribute the fresh water throughout the tank's volume. The incoming water creates a rolling action which will help to scour the work piece clean as well as dilute the drag-out throughout the tank's volume. The distribution line can easily be constructed by drilling holes at 3-inch intervals into a ½ or 1 inch PVC pipe and capping-off one end.

Air agitation will help remove any plating solution clinging to the surface of the work piece as well as mix the contents of the tank. Air can be introduced into the tank by an aerator placed diagonally across the bottom of the tank. This can be a commercially available aerator or one can be constructed by drilling 1/8 inch holes at 1 to 5 inch intervals in a 1 inch PVC pipe and capping-off one end. The total area of the holes must be somewhat less than the cross-sectional area of the pipe, but not less than 2/3 as this would put too much back pressure on the blower. The air pressure must be supplied by a blower, as an air compressor can contaminate the solution with oil.

A flow control valve is used to restrict the fresh water feed rate to an optimum level. The simplest and least expensive type is a mechanical flow control valve. This type of valve will maintain a specific flow rate independent

of the water faucet setting. These flow controllers are usually rated in ½ gpm intervals from 1 gpm, and are available in plastic or plated brass.

An alternative is the use of a conductivity control system. This uses a conductivity probe to measure the level of dissolved solids in the rinse tank. When the level exceeds a predetermined maximum value, the controller will open the fresh water feed valve. When the level reaches a preset minimum valve the water flow is stopped. This type of system is best used when the amount and type of work varies greatly from day to day. The major draw backs to this type of system are the relatively high system cost, difficulty in establishing the concentration limits and the need for regular system maintenance.

Capital and Operating Costs

These water conservation techniques are very inexpensive to install and operate. The typical costs of these techniques are detailed below:

- Water distribution line: The cost of 8 feet of ½ inch PVC pipe, necessary connections and an end cap is about $30 installed.
- Aerator: A commercially available aerator costs about $60 installed. An in-plant fabricated unit will cost about the same amount.
- Flow control valve: The installed cost of a mechanical flow control valve is about $10 for a metal valve and $25 for a PVC valve. These valves are available from local plumbing supply houses. The conductivity control system will cost about $500 and up to purchase and install. These systems are available from a number of manufactures including Myron L (Carlsbad, California) and Beckman (Cedar Grove, New Jersey).

The total cost for installing a water distribution line, an aerator and a mechanical flow control valve would be about $100 for a typical rinse tank.

There are no direct operational costs associated with these techniques. Though, they should be included in the facility's routine inspection and maintenance program.

Pay Back

The pay back period for installing or retrofitting these water conservation techniques into a rinse tank will depend on the quantity of water saved, as well as the water and sewer costs. For example, if water flow is reduced from 6 gpm to 3 gpm, and the water and sewer charges are $2/1000 gallons, the pay back period will be about 7 weeks for a typical rinse tank. After this initial pay back period the water conservation system will reduce operating costs by $750 per year, through water savings.

In addition to these direct cost savings, a water conservation program can reduce the capital cost of any required end-of-pipe wastewater treatment system. A rough "rule of thumb" is that a precipitation system costs about $2,000 per gallon of flow per minute. Thus a substantial reduction in water flow can produce corresponding savings in treatment system costs. However, small or token reductions will yield very little, if any, savings.

Selected References

1. JRB Associates. Three Case Studies to Improve Industrial Waste Management in Baltimore-Area Metal Finishing Plants. 83-4, Maryland Hazardous Waste Facilities Siting Board, Annapolis, Maryland. 1984.
2. Kushner, J. B. and A. S. Kushner. Water and Waste Control For the Plating Shop. Second Edition. Gardner Publications. Cincinnati, Ohio. 1981.
3. Roy, C. H. In-Plant Conservation. American Electroplaters' Society. Winter Park, Florida. 1980.

Additional Information

For additional information on water conservation in the electroplating industry or other pollution prevention techniques, contact:

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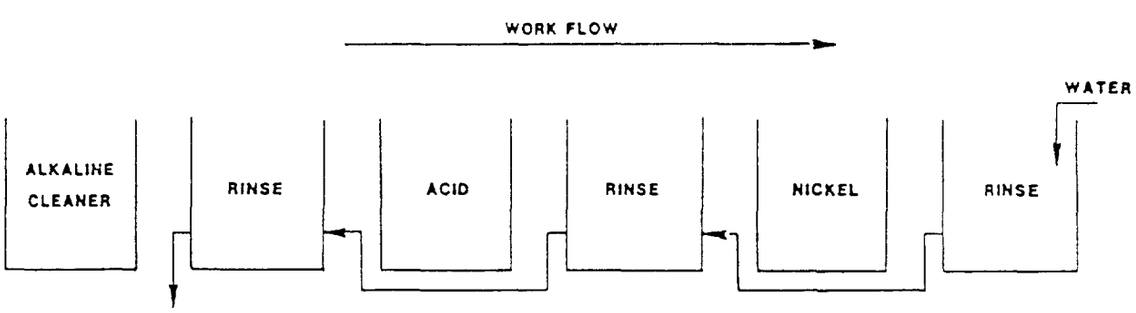
POLLUTION PREVENTION TIPS

WATER CONSERVATION FOR ELECTROPLATERS: RINSE WATER REUSE

Techniques for Rinse Water Reuse

Rinse water does not have to be discharged to the sewer after it is used only once, but can be recycled through the production line. This technique for water reuse, known as reactive rinsing, takes advantage of the chemical makeup of the rinse water to not only reduce water usage but to actually increase rinsing efficiency, thus improving plating quality.

A good example of this technique can be found in the nickel plating line. As shown below, water consumption can be reduced by two-thirds in a typical line by recycling the rinse water.

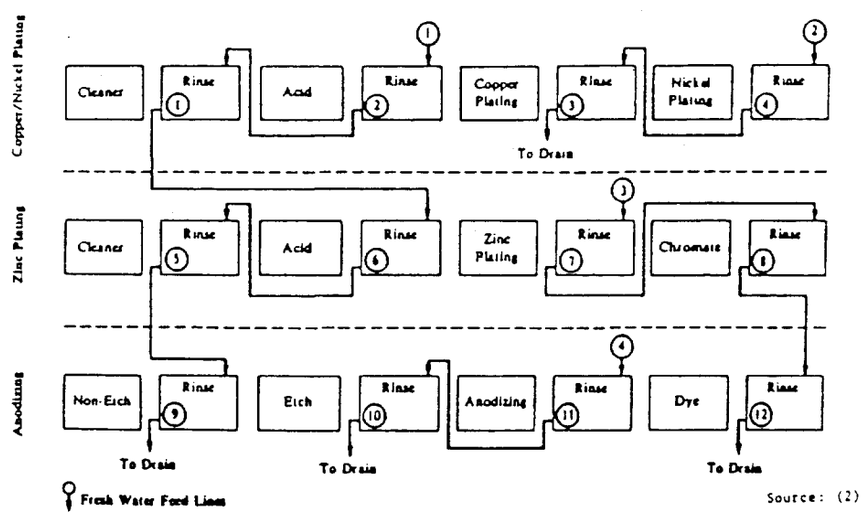


Nickel Plating Line

In this example nickel rinse water is recycled back to the acid dip rinse tank. This allows nickel plating solution dragged out of the process bath to be dragged back into the bath. This will not harm the rinse step and will allow the fresh

water feed to the acid rinse tank to be turned off. The acid rinse water can then be recycled to the alkaline cleaner rinse tank. This not only allows the feed water to this tank to be shut off, but it will improve the rinsing efficiency by helping to neutralize the dragged in alkaline solution. This will prolong the life of the acid bath as the rinse water dragged into it will already be partially neutralized. Thus the acid bath will not have to be dumped as often. In this example rinse water use was reduced from 9 gpm to only 3 gpm.

This concept can be taken one step further and the rinse water can be recycled between process lines. One facility used this technique to reduce water usage in three process lines from 48 gpm to 16 gpm by being able to shut off 8 fresh water feed lines. The scheme used is shown below:



Example of Interprocess Reactive Rinse System

Some replumbing is all that is needed to set-up a rinse water reuse system. The rinse water can be either gravity fed or pumped to the next rinse tank. Only a small amount of head pressure is needed to run a gravity system. One way to

supply this pressure is to use building bricks to elevate the tanks. PVC pipe can then be used to connect the tanks together. If the rinse tanks cannot be elevated or the water must be piped across the shop, then a pump system can be used. A simple system can be constructed by using small submersible pumps (2-5 gpm) and ½" PVC pipe. As a safety measure level controls can be added to regulate the flow of water between tanks.

The reuse of rinse water cannot be used indiscriminately as it could contaminate process baths and reduce plating quality. However, if care is taken in evaluating each potential use, then the use of this technique can produce significant water savings.

Capital and Operating Costs

Rinse water reuse is one of the most cost effective water conservation techniques available. The typical costs per application (i.e. connecting together 2 rinse tanks) is shown below:

- Gravity fed system:
  - Cost of 10 feet of ½" PVC pipe and necessary fittings is about $5.00.
  - Cost of installation, 4 man hours, and contingencies is about $85.00.
  - Total cost is about $90.
- Pump system
  - Cost of a 3 gpm submersible pump, 30 feet of ½" PVC pipe and necessary fittings is about $70.
  - Cost of installation, 8 man hours, and contingencies is about $180.00.
  - Total cost is about $250.

There is no direct operational costs associated with this technique. However, the equipment should be included in the facility's routine inspection and maintenance program.

Pay Back

The pay back period for installing a rinse water system will depend on the quantity of water saved and the water costs. For example, if a system is installed on a typical nickel plating line the water flow rate can be reduced from 9 gpm to 3 gpm. Assuming water and sewer charges are $2/1000 gallons, then the pay back period for a gravity system will be about 6 weeks and for a pump system it will be about 18 weeks. After this initial pay back period the water reuse system will reduce operating costs by $1,500 per year, through water savings.

In addition to these direct costs savings, a water conservation program can reduce the capital cost of any required end-of-pipe wastewater treatment system. A rough "rule of thumb" is that a precipitation system costs about $2,000 per gallon of flow per minute. Thus a substantial reduction in water flow can produce corresponding savings in treatment system costs. However, small or token reductions will yield very little, if any, savings.

Selected References

1. Kushner, J. B. and A. S. Kushner. Water and Waste Control For the Plating Shop. Second Edition. Gardner Publications. Cincinnati, Ohio. 1981.
2. Saltzberg, E. R. "A Manual of New Waste and Water Conservation and Reuse Methods for the Electroplating Industry". Presented at the 1983 Triangle Conference on Environmental Technology. Chapel Hill, North Carolina. 1983.
3. JRB Associates. Three Case Studies to Improve Industrial Waste Management in Baltimore-Area Metal-Finishing Plants, 83-4. Maryland Hazardous Waste Facilities Siting Board, Annapolis, Maryland. 1984.

Additional Information

For additional information on water conservation in the electroplating industry or other pollution prevention techniques, contact:

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WATER AND CHEMICALS REDUCTION FOR COOLING TOWERS

Are you pouring money down the drain? Are you operating a cooling tower in the once-through mode or relying on manual control of air-conditioner bleed-off rates? This may result in undue expenses in the form of unnecessary chemical, energy, labor, and water costs. A once-through system employs no conservation practices and is the most expensive alternative in most instances. The manual bleed/feed approach is at best a calculated gamble, and it may lead to water pollution or operational problems. Random manual bleeding of the system to control the dissolved solids and manual addition of chemicals does not take into account the variability of the loading on a system from day to day. Instead the bleed/feed approach is usually based on "average" conditions. When the loading exceeds this average an insufficient volume is bled off and the solids level becomes too high. The converse is true as well; below average loading results in excessive bleed off of water.

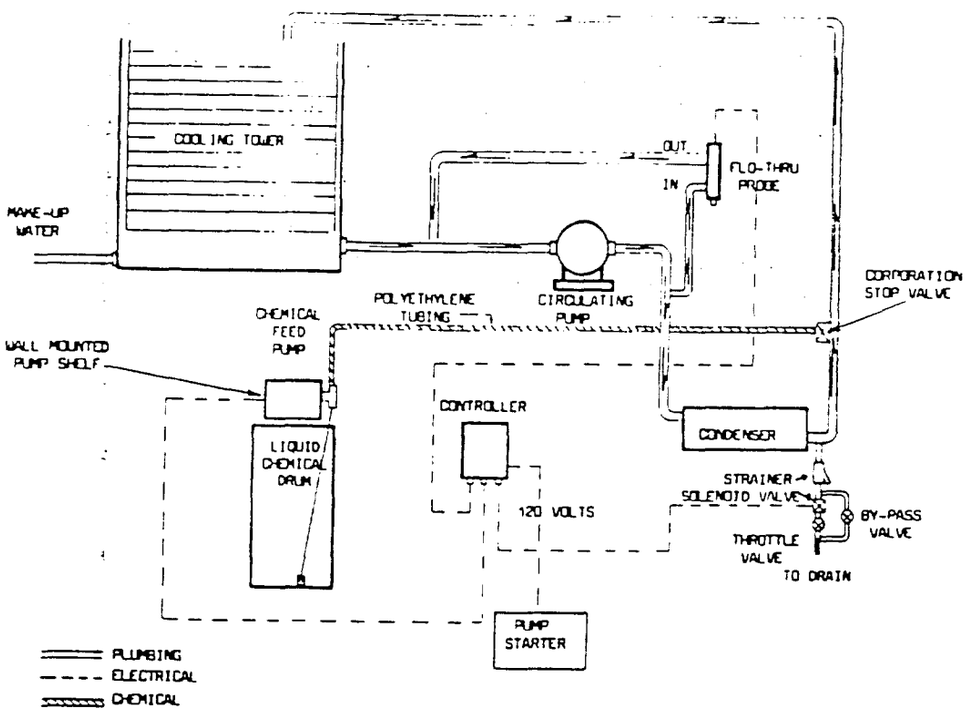
An automated bleed/feed system can reduce water consumption by as much as 60 percent. The cost savings can pay for the controls in a very short period of time. As an example, with combined water and sewer rates of $2/1000 gallons, reducing the water usage by just 1 gpm can save $1000 annually. With a large system, the savings can add up to thousands of dollars annually. When this is added to the reduced operating costs (chemical and energy) the savings are even greater.

The chemical composition of the cooling water must be maintained at the proper level for the system to operate efficiently. Proper control is also necessary to protect the air conditioning equipment. Maintaining cooling water composition is accomplished by: (1) bleeding tower water from the system to overcome the concentrating effects of evaporation and (2) pumping the appropriate quantity of chemicals into the cooling water. Excessive bleeding or chemical addition to the system will result in the discharge of excess chemical conditioners and/or active biocides thereby causing or contributing to water pollution or toxicity problems. Using automatic bleed/feed controllers is a practical approach to reducing the operating costs and minimizing waste from a cooling tower. A diagram of an automated system is shown in Figure 1.

Automatic controllers continuously monitor the concentration of dissolved material in the cooling water. When the concentration

exceeds a preset level, the controller opens the bleed valve and activates the chemical feed pump. Thus the tower is kept at the optimum concentration at all times and unintentional discharge of active chemicals is eliminated. This results in a cost savings in many areas. Labor costs for cleaning and manually adjusting chemical feed rates are reduced. Energy consumption is lowered by minimizing scale build up on the heat exchanger surfaces (scale acts as an insulator, thereby reducing the efficiency of the unit). The consumption of both chemicals and water is reduced by avoiding excessive bleeding during periods of lower air conditioning load.

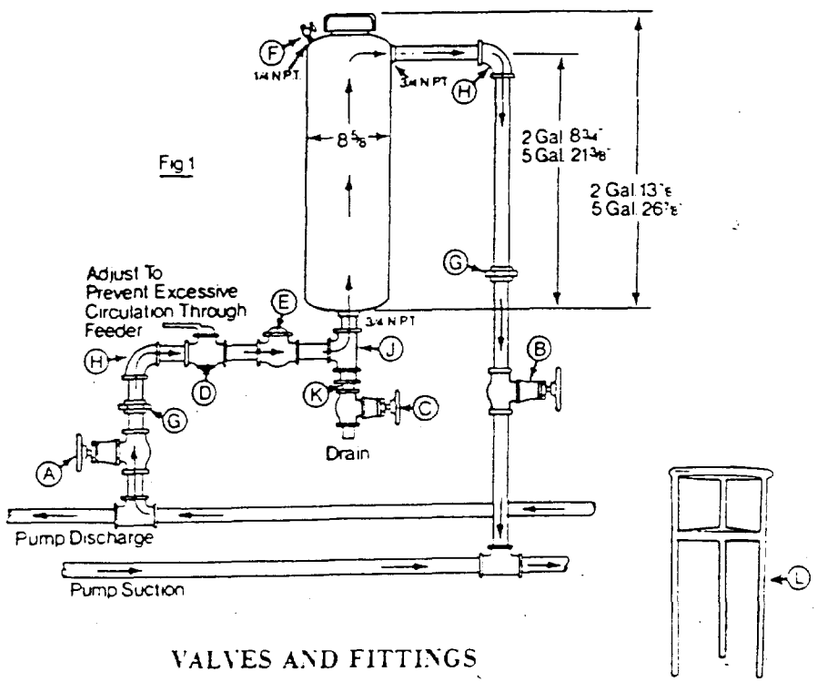
FIGURE 1. AUTOMATIC FEED AND BLEED-OFF SYSTEM FOR COOLING TOWERS



(Provided by the N.C. Department of Administration)

A bypass feeder (shown in Figure 2) can be easily incorporated into the system to safely introduce chemicals to prevent biological fouling and minimize bacterial growth. The proper feeding of these biocides, periodic dosing combined with temporarily switching off the automatic controllers, provides a means of obtaining maximum biological control while minimizing chemical usage and the potential discharge of toxic chemicals.

FIGURE 2. BY-PASS FEED SYSTEM FOR ADDING BIOCIDES TO COOLING TOWERS



VALVES AND FITTINGS

	Function	Description
A	Inlet Valve	3/4" Gate Valve
B	Outlet Valve	3/4" Gate Valve
C	Drain Valve	1/2" Globe Valve
D	Control Valve	3/4" Ball Valve
E	Check Valve	3/4" Check Valve
F	Vent Valve	1/4" Petcock
G	Union	3/4" Union
H	Elbow	3/4" Elbow
J	Tee	3/4" Tee
K	Reducer	3/4" to 1/2" Bushing with Nipple
L	Holds Feeder	Tripod Stand

Optional: D & E

(Provided by the N.C. Department of Administration)

Capital and Operational Costs

Automatic bleed/feed controllers and by-pass feeders are not expensive to install or operate. The typical costs for these controls are detailed below.

- Controller: A commercially available controller complete with conductivity probe can be obtained for $325. Installation for the controller will add and additional $75. Several systems are available. The Pollution Prevention Program can provide a list of vendors if desired.

- Chemical Feed Pump: A chemical feed pump and associated appurtenances can be obtained for about $150.

- By-Pass Feeder: A by-pass feeder for adding biological control agents in the cooling system can be obtained for about $150.

The total cost for installing an automatic bleed/feed system and the equipment to introduce biological control agents into the system would be about $1000.

There are no direct operational costs associated with the automatic bleed/feed system. However, the units must be included in the facility's routine inspection and maintenance programs.

Pay Back

The pay back period for installing automatic bleed/feed controls will depend on several factors such as the quantity of water saved, including both water and sewer costs; savings resulting from reduced chemical costs; energy savings; and reduced labor costs. As an example, the North Carolina Department of Administration has installed automatic bleed/feed systems on fifteen air conditioning systems in government office buildings at a total investment of $15,000. The Department has reported a payback period of five (5) weeds and total annual savings of $149,000 as a result of the automated system. The Department of Administration is now recommending that all State owned cooling towers and air conditioners by fitted with bleed/feed controllers.

Specific water, energy, chemical, and labor cost savings experienced by the Department of Administration are as follows:

- Chemicals The chemical costs have been cut from $17,300/yr to $5,445/yr. (Savings = $11,855).

- Energy — The energy savings as a result of the automation has been determined to be 13 percent. At $0.05/KWH this translates into an annual savings of $68,842.

- Labor — All chillers require cleaning and rodding at least annually. Assuming an hourly wage of $8.00, the labor costs for cleaning and rodding were reduced by $2,400/yr due to less frequent need for cleaning. Labor costs for daily manual adjustments of the chemical feed and tower bleed rates were $2,826. (Total savings = $5,226).

- Water — Since the installation of automatic bleed/feed controllers cooling water is now used for 4.5 cycles as opposed to 1.5 cycles before. This saves 34,900,000 gallons of water annually. Based on a combined water and sewer rate of $1.83/1000 gallons, the annual savings is $63,900.

Additional Information

For additional information on automatic bleed/feed systems for cooling towers, contact:

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POLLUTION PREVENTION TIPS

COOLANT MANAGEMENT

As a way to reduce the increasing costs of purchasing coolant concentrate, many companies are implementing coolant management programs. Reasons for reclaiming coolants regularly include longer tool life, decreased reject rates, improved surface finishes, and provisions for a cleaner, odorless work area.

The primary reasons that coolants are discarded are the buildup of solids, bacterial growth, and excessive tramp oil in the coolant. If on a regular basis coolants are removed from the machine sumps, treated to remove these contaminants, and brought back to specification by adding new coolant concentrate, the amounts of coolants used yearly could be drastically reduced. Approximately 10% of the coolants are lost to dragout and evaporation. Replenishing this 10% with new makeup solution usually maintains biocide levels, but other additives such as rust inhibitors may also be needed.

Reducing Tramp Oils in Coolants - Since tramp oils such as hydraulic and lube oil are major causes of coolant breakdown and rancidity associated with the formation of hydrogen sulfide; all hydraulic oil leaks should be repaired. A preventative maintenance program to periodically inspect and replace gaskets, wipers, and seals should be performed.

Coolant Selection - Use only quality stable cutting and grinding fluids with the best recyclability. Examine the coolants for resistance to bacterial attack, corrosion protection, residues left on work pieces, and hazardous additives when evaluating cutting and grinding capabilities. Try to reduce the number of different coolants being employed to more easily facilitate recycling. Sometimes only the coolant concentration needs to be changed for different applications.

Coolant Makeup Water - Tap water with a high mineral content can adversely affect coolant performance by deteriorating emulsions, causing corrosion, and enhancing microbial growth. Purification of makeup water through deionization can help. You may want to explore the possibilities of using deionized wate for coolant bath makeup water.

Coolant Concentration and Chemistry - Refractometers or titration kits should be made available to operators (along with training on how to use them) to monitor and maintain proper coolant concentrations. Refractometers cost between $150 - $200. Low pH readings signify low coolant concentrations and related problems of increased metal fines and suspended solids. Also, a drop in pH can be due to increased microbial growth.

Sump Maintenance - Another step that can be taken to reduce the required frequency of coolant treatment or coolant dumps is to install oil skimming devices on each machine sump. By removing excess tramp oil from the sump, you will be removing part of the food source for bacteria which causes the coolant to turn rancid. A number of companies make oil skimming devices which remove floating tramp oils. Skimming wheels cost between $100 - $500. It is necessary for the sump to be still while the oil skimmer is operating, otherwise the oils will not float to the top to be skimmed. A good time to operate the oil skimmer is during lunch break. The oil that is skimmed from each sump could be collected and managed as waste oil.

To help extend the life of the coolant, machine sumps clean-out should be scheduled on a regular basis. The frequency will of course depend upon the use of the machine. It is particularly important that the shavings be removed and the sumps cleaned with an alkaline cleanser when dirty coolant is removed from the sump for cleaning or disposal. The built-up metal shavings harbor bacteria which can recontaminate the new or rejuvenated coolant. These areas with built-up shavings are also somewhat impenetrable to the biocides contained in the coolant.

Coolant Circulation - With the exception of the times when the sump is still to operate the oil skimmer, the sump should remain agitated. Bothersome anaerobic bacteria are able to grow and reproduce much more rapidly in a stagnant sump than in a well-agitated sump.

Coolant Recycling Equipment

There are many different types of equipment available for recycling coolants. This equipment ranges from simple filtration or oil skimming equipment to multiple stage machinery incorporating filtration, centrifugation, and heat pasteurization.

Centrifugation - This process involves mechanical rotation of the coolants to provide several thousand G's of separating force. Centrifugation is able to remove hydraulic oils and other emulsified tramp oils as well as free floating oils and solids.

Coalescing Separators - This technique uses an olephilic high surface area medium to coalesce oil to form larger droplets. These larger oil droplets float to the surface and can be skimmed off using adjustable weirs. Coalescers are not effective for removing water miscible hydraulic oils or other emulsified oils.

Hydrocyclones - This process uses centrifugal force to remove solids from the fluid. It is not effective for removing small quantities of tramp oil, but can remove solids down to 5 microns. This system is mechanically simple and easy to operate.

Proper Trash Disposal

Care must be taken to keep cigarettes, napkins, chewing tobacco and other trash out of the coolant sumps and chip bins. Cleanliness fosters good work habits and can have a positive impact on coolant recycling efforts.

Conclusions

Proper coolant management and coolant recycling are effective ways for metalworking operations to save money on raw materials and waste management and to reduce waste generation. For more information about coolant management contact:

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WATER CONSERVATION FOR TEXTILE MILLS

Techniques

Are you pouring money down the drain? You are if your firm does not have a water conservation program. Water is expensive to buy, treat, and dispose of. A water conservation program can cut water consumption by up to 30%, or even more, and the cost savings can pay for the required materials in a very short period of time. For example, with average water and sewage rates about $2/1000 gallons, reducing the flow to a washer by just 1 gpm can save $250 per year. With the large number of washers in an average plant, the savings can add up to thousands of dollars per year. Add to this the reduced capital costs of a waste treatment system and the savings can be even greater.

There are numerous methods which have been developed to conserve water at textile mills. Some of the techniques applicable to a wide variety of firms are discussed below:

Counter-current Washing. This measure is employed frequently on continuous preparation and dye ranges for water and energy savings. Clean water enters at the final wash box and flows counter to the movement of the fabric through the wash boxes. Thus, the cleanest water contacts the cleanest fabric, and the more contaminated washwater contacts the fabric immediately as it (the fabric) enters the actual process. This method of water reuse is opposed to the traditional washing method of supplying clean

water at every stage of the washing. Water and energy savings are related to the number of boxes provided with counterflow. Countercurrent washing can be applied at desize washers, scour washers, mercerizing washers, bleach washers, dye ranges, and printhouse soaper ranges.

Reuse of Final Rinse Water from Dyeing for Dye Bath Make-up. The rinse water from the final rinse in a batch dyeing operation is fairly clean and can be used directly for further rinsing or for make-up of subsequent dyebaths. Several woven fabric and carpet mills use this rinse water for dyebath make-up.

Reuse of Soaper Wastewater. The colored wastewater from the soaping operation can be reused at the backgrey washer, which does not require very high quality water. Alternatively, it can be used for cleaning floors and equipment in the print and color shop.

Reuse of Scouring Rinses for Desizing. The rinsewater from the scouring operation is adequate for reuse in other processes that do not require extremely high water quality, such as desizing. This is particularly true with scouring wastes from synthetic or cotton/synthetic blend fabrics. Scouring rinses may, in certain cases, also be reused for the washing of floors and equipment.

Reuse of Mercerizing or Bleach Washwater for Scouring or Desizing. Mercerizing or bleaching rinsewater can be used in scouring and desizing operations as long as size recovery is not practiced. The caustic or bleach stream will generally degrade many size compounds to an extent that they cannot be recovered.

Recycle/Reuse of Water Jet Weaving Wastewater. The jet weaving wastewater can be reused within the jet looms. Alternatively it can be

reused in the desizing or scouring process. This is provided that fabric impurities and oils are removed by in-line filters.

Use of Automatic Shutoff Valves. An automatic shutoff valve will control the flow of water into a process unit based on time, level or temperature. One plant estimated that a reduction in water use of up to 20% could be achieved with thermally controlled shutoff valves.

Use of Flow Control Valves. A flow or pressure reduction valve can significantly reduce the quantity of water used in a wash or clean-up step. They are particularly useful in cleaning areas where operators are not always conscious of the need for water conservation.

Good Housekeeping. A program of maintenance, inspection and evaluation of production practices should be established. Significant water reductions can be made through such areas as minimizing leaks and spills, proper maintenance of production equipment, identification of unnecessary washing of both fabric and equipment, and employee education on the importance of water conservation.

These water conservation techniques are not without their drawbacks. Some of the techniques can adversely affect size recovery practices, impact quality of fabric and manufacturing processes, and be limited by physical plant constraints. However, since these measures are generally cost effective, each mill must evaluate the merits of a particular application within the physical and processing constraints of the mill.

Capital and Operating Costs

The equipment used in a water conservation program is relatively inexpensive. In most cases it will consist of only valves, piping,small pumps and

tanks. The operating costs for these systems are usually very low. The major portion of the cost would be for routine maintenance and in some cases electricity for the pumps.

For example, the cost of purchasing and installing the equipment necessary to reuse 75,000 gallons per day of bleach wastewater for scouring, is as follows:

Pump	$ 3,000
Tank/Sump	14,000
Piping	5,000
Electrical	1,000
Total Cost	$23,000

The yearly operating costs are estimated to be $1,300. This includes the electrical power for the pumps and routine maintenance.

Pay Back

The pay back period for a water conservation system will depend on the quantity of water saved, the cost of raw water, sewer fees and wastewater treatment costs. For example, the system discussed above would have a 3 month pay back period. After this initial period the system would save the company over $95,000 per year in reduced water, sewer and energy costs.

In addition to these direct cost savings, a water conservation program can reduce the capital cost of any required end-of-pipe wastewater treatment system. A treatment system can cost several thousands of dollars per gallon of flow per minute. Thus a substantial reduction in water flow can produce corresponding saving in treatment system costs. However, small or token reductions will yield very little, if any, savings.

Selected References

1. Bergenthal, J. F. Wastewater Recycle and Reuse Potential for Indirect Discharge Textile Finishing Mills: Volume I-Technical Report. EPA-600/2-84-070a. U.S. Environmental Protection Agency, Research Triangle Park, NC. 1984.

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3. Environmental Pollution Control: Textile Processing Industry. EPA-625/7-78-002. U.S. Environmental Protection Agency, Cincinnati, OH. 1978.

Additional Information

For additional information on water conservation techniques or other pollution prevention methods, contact:

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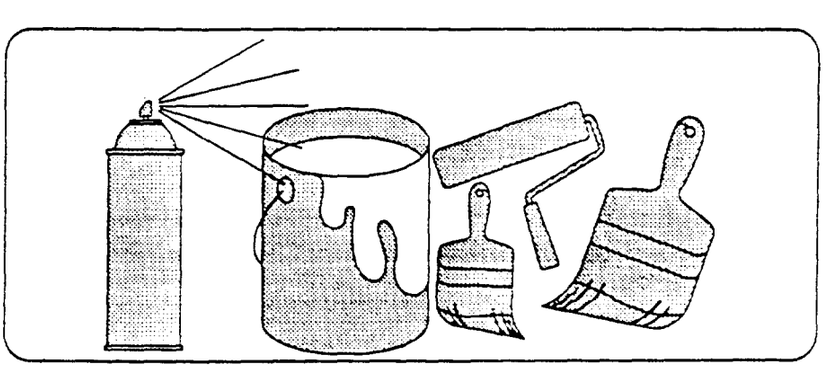
POLLUTION PREVENTION TIPS

Overview of Coating Technologies

Prior to 1966, before the first U.S. environmental regulation was adopted, almost every item that was painted was finished with low-solids solvent-borne coatings. Since that time, however, environmental concerns and the increasing cost of solvents have created demand for chemical formulations and coating application techniques that will reduce air emissions and save raw materials. This demand increased dramatically with the passage of the 1990 Clean Air Act Amendments.

Typical solvent-based paints contain 60 to 80 percent volatile organic compounds (VOCs), many of which are also listed as hazardous air pollutants (HAPs) or toxic air pollutants. A number of new resins are being introduced into the coatings market designed to improve performance, especially in high-solids and waterborne formulations. In addition to new coating formulations, technologies are changing rapidly to improve efficiency in coating applications.

To encourage pollution prevention in coating operations, the Pollution Prevention Program (PPP) provides this TIP on the advantages and disadvantages of various coating formulations and application technologies. Since many variables are involved in the selection of the most efficient technology, or combination of technologies, the PPP hopes that this information will serve as a guide in making those decisions.



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N.C. Department of Environment, Health, and Natural Resources

June 1993

Coating Formulations

High Solids

High solids coatings are solvent-based and have a high resin concentration. Solids content typically falls in the 50 to 70 percent range, although some formulations are higher.

- Advantages
  - Reduced VOC and HAP emissions
  - Reduced solvent usage
  - Reduced inventory
  - Reduced fire hazards
  - Reduced number of spray applications to achieve a given film thickness
  - Improved abrasion and mar resistance

- Disadvantages
  - Generally require high cure temperatures
  - Sensitive to inadequate cleaning of substrate
  - Extremely sensitive to temperature and humidity
  - Difficult to control film thickness
  - Tacky overspray difficult to clean
  - May require paint heater in system
  - Difficult to control sagging
  - Narrow "time-temperature-cure" window
  - Cannot use dip or flow coating
  - Difficult to repair

Waterborne Coatings

In waterborne coatings, water, alone or in conjunction with an organic solvent, acts as the carrying medium. Most waterborne coatings contain an organic co-solvent (usually 2 to 30 percent) that is added to dissolve the resin.

- Advantages
  - Reduced VOC and HAP emissions
  - Conventional application processes can be used
  - Reduced toxicity and odor, resulting in improved worker safety and comfort
  - Good storage life
  - Easy clean-up
  - Reduced fire hazard
  - Disposal of hazardous waste minimized or even eliminated

- Disadvantages
  - May cause grain raising in wood
  - Tendency to foam
  - Rubbing requires effort
  - Surface must be free of oil and dust
  - Longer drying times or increased oven temperatures required
  - High gloss finish difficult to obtain
  - Clean-up difficult once coating is cured
  - Great susceptibility to dirt pick-up
  - Most of these coatings cost more per gallon on an equivalent solids basis
  - Not many resins available for waterborne formulations
  - Converting solvent-borne coating line may be complex, i.e., stainless steel or plastic lines, valves, etc., are needed
  - Problems with atomization, i.e., reduced paint transfer efficiencies
  - Increased runs and sags
  - Needs good temperature/humidity control
  - Storage area requires enclosure and heating
  - Refinishing is difficult

Powder Coatings

Powder coatings contain 100-percent resin in dry powdered form and a built-in curing agent.

- Advantages
  - Cost savings due to:
    - No solvent flash required
    - No coatings mix room needed
    - Minimal oven length required
    - Low ventilation requirement
    - Floor space economy, i.e., system requires two-thirds to three-quarters of wet paint systems
    - VOC and HAP compliance, i.e., no solvents
  - Quality finish
  - Durable finish
  - Good corrosion resistance
  - Coating utilization efficiencies can reach 95 to 99 percent
  - Energy savings
  - Little operator expertise required
  - Quick "packagebility"
  - Variety of resins available
  - No hazardous overspray, waste sludge, or contaminated water
  - Reduced worker exposure to solvent vapors

- Disadvantages
  - Heat requirement restricts powder to metal finishing
  - Powder manufacturing limitations
    - Difficult to make small amounts
    - Control of texture size and distribution limited
    - Metallic powder coatings not as attractive as wet metallic finishes
  - Recirculating system creates negative pressure in booth
  - Need gentle air stream to apply powder
  - Enhanced Faraday cage effect
  - Difficult to achieve thin films below 1.0 to 1.5 mils
  - Powder clumping
  - Difficult to change colors
  - Needs cool, dry storage area
  - Powder coatings difficult to match for repair with liquid paint and hard to strip
  - Pretreatment of substrate is critical

UNICARB™ Spray System

In the UNICARB™ system, super-critical carbon dioxide replaces a substantial amount of the conventional solvents used to spray-apply industrial coatings.

- Advantages
  - High quality finish
  - Fewer coating applications needed
  - Reduced VOCs and HAPs
  - Reduced operating costs
  - Easy to retrofit
  - High transfer efficiency
  - May reduce sanding requirements for wood furniture
  - Reduced worker exposure to solvent vapors

- Disadvantages
  - Limited experience
  - Lower fluid delivery rates than airless or air spray guns
  - Gun and supply tubing is bulky
  - Royalty costs

Radiation-Cured Coatings

For radiation-cured coatings (ultraviolet (UV), electron beam (EB), and infrared (IR)), electromagnetic radiation is used to alter the physical and chemical properties of a coating such that the organic substrate develops cross-linked or solvent-insoluble network structures.

- Advantages
  - UV and EB technologies use coatings with lower VOC and HAP content than conventional coatings
  - IR ovens oxidize various VOC's, thus reducing potential emissions
  - Increased production rates because of short curing periods
  - Low energy costs
  - Consistent performance
  - Small ovens required
  - Low air movement reduces dust and dirt contamination
  - Easily installed/retrofitted
  - Reduced fire and explosion hazard
- Disadvantages
  - Interference of photocure by pigments
  - Higher capital investment than conventional ovens
  - Higher costs for EB and UV coatings
  - Potential problems with acrylate toxicity
  - Shrinkage and adhesion problems with acrylate
  - Not applicable to all finish types because it produces a specific "look"
  - Dermatitis
  - Curing sensitive to shape of part

Two-Component Reactive Liquid Coatings

In a two-component reactive liquid coating system, two low-viscosity liquids are mixed just before they enter into the application system. One liquid contains reactive resins, and the other contains an activator or catalyst that promotes polymerization of the resins.

- Advantages
  - Low-temperature processing
- Disadvantages
  - Limited experience
  - Uncured resin may be harmful
  - Highly complex process
  - High level of operator skill required
  - High capital cost
  - Limited pot life

Vapor Permeation of Injection-Cured Coatings

After a reactive resin is applied as a liquid, curing is induced by exposing the liquid to a vapor containing a compound that initiates polymerization. One example is polyol-isocycanate coatings cured by tertiary amine vapor injection.

- Advantages
  - Eliminates or reduces solvent
  - Low temperature processing
  - Unreacted overspray can be collected for reuse
  - Can be used on heat sensitive substrates
- Disadvantages
  - Limited experience
  - Highly complex process
  - High level of operator skill required
  - High capital cost

Application Technologies

Low-Volume High-Pressure (Conventional) Spray (LVHP)

LVHP spray guns operate with compressed air from an air compressor to atomize the paint. Pressures typically range from 40 to 70 pounds per square inch (psi).

- Advantages
  - Excellent atomization permits high quality finish
  - High production rates
- Disadvantages
  - Extensive overspray
  - Booth clean-up cost
  - Filter replacement cost
  - Waterwash reservoir treatment costs
  - High VOC and HAP emissions

High-Volume Low-Pressure (HVLP)

HVLP spray guns operate with a high volume of air delivered at 10 psi or less to atomize the paint.

- Advantages
  - Reduced overspray
  - Increased transfer efficiency
  - Reduced paint waste
  - Lower booth clean-up costs
  - Reduced filter replacement costs
  - Decreased waterwash reservoir treatment costs
  - Reduced VOC and HAP emissions
  - Portable and easy to clean
  - Sprays well into recesses and cavities
  - Reduced worker exposure to blowback
- Disadvantages
  - Atomization may not be sufficient for fine finishes
  - High production rates may not be possible

Airless Spray

In an airless spray gun, the paint is atomized by increasing the paint's fluid pressure (ranges from 500 to 6,500 psi) without introducing a pressurized air flow.

- Advantages
  - High rates of paint flow
  - Relatively high transfer efficiency
  - Gun handling versatility (no air hose)
  - Ability to apply highly viscous fluids
- Disadvantages
  - Relatively poor atomization
  - Expensive nozzles
  - Reduced fan pattern control
  - Coatings limitation
  - Tendency for tip plugging
  - Skin injection danger
  - Increased operator training required
  - Increased maintenance requirement

Air-Assisted Airless

About 150 to 800 psi of fluid pressure and 5 to 30 psi of air pressure are used in an air-assisted airless gun to atomize the paint.

- Advantages
  - Good atomization, but not as good as air
  - Varied fluid delivery
  - Low bounceback
  - High paint transfer efficiency
- Disadvantages
  - Skin injection danger
  - Increased maintenance required
  - Increased operator training required
  - Capital cost

Electrostatic Spray

With an electrostatic spray gun, the atomized paint droplets are charged at the tip of the gun by a charged electrode. The part to be painted is electrically neutral, and the charged paint droplets are attracted to the part.

- Advantages
  - High transfer efficiency
  - Good edge cover
  - Good wraparound
  - Uniform film thickness
- Disadvantages
  - Guns tend to be bulky and delicate
  - Extra cleanliness essential
  - Faraday cage effect
  - Safety/fire hazard
  - Parts must be conductive
  - High equipment and maintenance cost

Rotary Atomizers

Instead of air or fluid pressure, rotary atomizers use centrifugal force to atomize the paint and electrostatic charging to attract the paint to the part.

- Advantages
  - Excellent atomization
  - High solids, waterborne versatility
  - Viscosity flexibility
  - High transfer efficiency
- Disadvantages
  - Extra cleanliness essential
  - Faraday cage effect
  - Safety/fire hazard
  - Parts must be conductive

Roll Coating

With roll coating, the paint is applied by one or more auxiliary rolls onto an application roll, which then rolls across the conveyed flat part.

- Advantages
  - High transfer efficiency
  - High production rates
- Disadvantages
  - Cannot paint hard-to-reach areas
  - Limited to flat work

Dip Coating

Parts are painted by dipping them (usually by conveyor) into a tank of the paint.

- Advantages
  - High production rates
  - Low labor requirements
  - High transfer efficiency
- Disadvantages
  - Extremely dependent on viscosity of the paint
  - Not suitable for items with hollows or cavities
  - Color change slow
  - Fire hazard
  - Poor to fair appearance

Flow Coating

In a flow coat system, 10 to 80 separate streams of paint are directed to coat all surfaces of the parts as they are carried through the flow coater on a conveyor.

- Advantages
  - High transfer efficiency
  - Low installation cost
  - Requires little maintenance
  - High production rates
  - Low labor requirement
- Disadvantages
  - Poor to fair appearance
  - Principal control of dry-film thickness is viscosity of paint

Curtain Coating

In curtain coating, a waterfall flow of paint coats a part conveyed horizontally. The paint flows at a controlled rate from a reservoir through a wide variable slot.

- Advantages
  - High transfer efficiency
  - Uniform coating thickness possible
- Disadvantages
  - Suitable only for flat work
  - Highly dependent on viscosity

Autodeposition

Autodeposition is an oxidation-reduction precipitation process used to deposit organic paint films onto iron, steel, zinc, and zinc alloy-plated substrates.

- Advantages
  - Excellent anticorrosion properties (no phosphate coating required)
  - 100-percent coverage of surfaces wetted (no Faraday cage areas)
  - Uses waterborne material
  - No external source of electricity
  -
- Disadvantages
  - Dull or low-gloss appearance
  - Few colors available

Electrocoating

In electrocoating, a paint film from a waterborne organic solution is electrically deposed onto a part.

- Advantages
  - Over 90 percent utilization of coating material
  - Very thin, uniform coating on all surfaces that can be reached by electricity
  - High production rates
  - Corrosion-resistant coating
  - Low VOC and HAP emissions
  - Process can be fully automated
  - Can apply second coat on uncured electrocoat

- Disadvantages
  - Substrate limitation
  - Separate lines needed for each color
  - High cost to install
  - Masking problems
  - Sophisticated maintenance requirements
  - Air-entrapment pockets
  - Bulk small-part coating difficult
  - Corrosion-resistant equipment required
  - De-ionized water required
  - Sanding/stripping difficult
  - High energy demands
  - Restricted to large volume finishing
  - Coating thickness limitation
  - High level of training needed for employees

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POLLUTION PREVENTION TIPS

General Waste Minimization Options for Metal Cleaning

I. Metal Cleaning

Metal cleaning is an essential function in manufacturing, repairing, and maintaining parts and equipment in industries such as furniture, machinery, electric and electronic equipment, instruments and metal fabricating.

The purpose of metal cleaning is to remove impurities from the metal surfaces in preparation of finishing processes such as electroplating and/or coating; a clean product diminishes the potential for rejects during further processing steps. The cleaning methods and materials used depend upon the type of contaminants, which typically are soils, rust, paint, and oil. Usually, because more than one type of contaminant is present on the metal surface, a series of cleaning operations is required to fully prepare a metal surface for its final treatment.

Below is a review of basic waste minimization options applicable to metal cleaning operations including strategies for developing pollution prevention techniques for most metal cleaning applications.

II. General Waste Minimization for Parts Cleaning

Each cleaning process generates a specific type of waste that must be managed and disposed. The costs of proper waste treatment and disposal, more stringent environmental regulations, and increased liability are forcing industries to re-evaluate wastes generation practices.

Waste minimization in metal cleaning operations can be accomplished through source reduction, material reuse, and product recycling. The following steps will assist in reducing wastes from most metal cleaning operations.

A. Preventing Surface Impurities

The primary step for control of surface impurities is to identify the sources of the pollutants. Surface pollutants can be incoming soils applied by metal vendors or contaminants such as coolants, stamping fluids, and rust inhibitors applied in-house.

- → Peel coatings or shrink wrap may substitute for protective coatings of grease or paint which require solvent removal. These coverings will prevent dust and oils from depositing on the metal surfaces during shipment, storage, and handling. Because the used wrapping materials may be sellable to a recycler, revenues may be generated and disposal fees may be eliminated.
- → Moisture which causes rust to form can also be eliminated or reduced by properly drying the parts between operations or by storing them indoors away from condensation or rain.

B. Selecting the Least Hazardous Cleaning Agent

Selection of a cleaning process for specific parts is determined by several factors including physical and chemical properties of contaminants, substrate surface, and cleaning media; the

amount of contaminant to be removed; the required level of cleanliness; the complexity of the surface to be cleaned; the quantity of parts to be cleaned; the costs of materials/equipment/labor; and worker/environmental protection.

In the search for a less polluting cleaning process, the user should select the least toxic and most environmentally friendly medium that performs with the desired efficiency. Below are cleaning media and the order in which they should be evaluated:

1. Water or air.
2. Abrasive media with water or air as carrier.
3. Aqueous solutions.
4. Acidic or caustic solutions.
5. Solvents.

A new cleaning process or any proposed process changes must be carefully evaluated for potential effects on substrate and downstream processes such as anodizing, plating, and painting. Additionally, all regulations and existing permits that the facility must comply with should also be evaluated for the effects of a process change.

C. Optimizing Cleaning Efficiency

If cleaning steps cannot be eliminated and the least toxic/hazardous materials are being used, the absolute smallest amount of cleaner necessary to obtain an acceptable product should be applied. Also, proper worker training and retraining are essential to ensure the materials are applied with the greatest achievable efficiency. Employees should also be given the opportunity to identify wastes and determine ways to eliminate and reduce them.

D. Segregating Wastes and Reuse/Recycling

Source segregation will minimize the amount of wastes generated and disposed and also save on purchases of raw materials. In the metal cleaning industry, separating, reusing, and recycling used solvents result in enormous economic and environmental savings. With careful attention to the following handling and safety tips, a facility can profit from successful waste segregation.

- The solvents should not be allowed to mix with contaminants such as water, solids, and garbage.
- Hazardous materials should be separated from non-hazardous so that the latter will not be misclassified as hazardous.
- All used solvent containers should be properly labeled, covered, and stored in a restricted area that is kept cool and provides containment in the event of a release.
- Employees working with any type of material whether new or spent should be trained on proper handling practices.
- To comply with applicable regulations and prevent a spill incident, the facility must ensure that required procedures are followed and personnel safety equipment is worn when workers handle any regulated raw materials or wastes.

Facility conditions such as space for materials storage and/or recycling equipment; costs of equipment, training, and manpower; and suitability to processes determine whether spent solvents may be segregated and recycled on- or off-site. For more information on solvent recycling from metal cleaning operations, call the N.C. Pollution Prevention Program at (919) 571-4100.

Chapter

3

Waste Reduction Techniques and Technologies

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3.1 Introduction to Waste Reduction Techniques

Waste reduction techniques can be applied to any manufacturing process, from something as simple as making a paper clip to something as complex as assembling the space shuttle. Available techniques range from easy operational changes to state-of-the-art recovery equipment.

The common factor in these techniques is that they reduce bottom-line operational costs.

Waste reduction is not a new concept—it has been around as long as humans have been producing products. While it has been known over the years by a number of names, it is merely optimization of the production process. For example, a late-eighteenth-century electroplating manual states that "nothing whatever should be allowed to go to waste in well-conducted works."[1] The manual includes many waste reduction methods that are applicable and are discussed in the literature even today. This points up the fact that many waste reduction techniques are relatively "low-tech." In fact, many industries find that simple operational changes, increased training, and improved inventory management can significantly reduce waste generation rates.

Waste reduction techniques can be broken down into four major categories, as shown in Table 3.1. Because the classifications are broad there will be some overlap. In actual application, waste reduction techniques generally are used in combination so as to achieve maximum effect at the lowest cost.

The selection of specific reduction techniques by an individual business must be based on accurate and current information on waste-stream generation and waste management costs. This is accomplished by developing and implementing a waste reduction program as a key part of a comprehensive waste management plan. Components of the reduction program include procedures for collecting information, evaluating options, and identifying cost-effective waste reduction techniques. Once identified, the techniques can be implemented and become an established part of the facilities management and operation. Approaches to developing such a program are discussed in Chap. 4.

TABLE 3.1 Categories of Waste Reduction Techniques

Inventory management
Inventory control
Material control
Production process modification
Operation and maintenance procedures
Material change
Process equipment modification
Volume reduction
Source segregation
Concentration
Recovery
On-site recovery
Off-site recovery

One point of caution: An evaluation should be made of a reduction technique's impact on all wastestreams, not just the targeted one. This thorough evaluation must be done before the technique is implemented. For example, while changing from a solvent to a water-based cleaner will eliminate the generation of hazardous waste, it may also increase the wastewater's organic load, possibly to such an extent that the facility cannot meet its discharge limits without incurring significantly increased wastewater treatment costs.

3.2 Inventory Management

Proper control over raw materials, intermediate products, final products, and the associated wastestreams is now being recognized by industry as an important waste reduction technique.[2] In many cases waste is just out-of-date, off-specification, contaminated, or unnecessary raw materials, spill residues, or damaged final products. The cost of disposing of these materials not only includes the actual disposal costs but also the cost of the lost raw materials or product. This can represent a very large economic burden on any company. For example, one furniture company had to spend thousands of dollars, at $5/gal, to properly dispose of two-years' worth of unused coating materials. This expense was in addition to the $7/gal the material originally had cost.[3]

There are two basic aspects to inventory management: controlling the types and quantities of materials in the plant inventory; and controlling the handling of raw materials, along with the finished products and wastestreams in the production facility. The former aspect, referred to as *inventory control*, includes techniques to reduce inventory size and hazardous chemical use while increasing inventory turnover. The latter aspect, referred to as *material controls*, includes methods to reduce raw material and finished product loss and damage during handling, production, and storage.

Any effective inventory management program must include process waste. Handling waste as if it were a product will help reduce waste and increase the potential for recovery. Many of the techniques discussed in this section can be applied to waste material as well as to raw materials and finished products.

3.2.1 Inventory control

Methods for controlling inventory range from a simple change in ordering procedures to the implementation of just-in-time (JIT) manufacturing techniques. Most of these techniques are well known in the

business community; however, their use as very effective waste reduction techniques has not been widely recognized. Many companies can help reduce their waste generation by tightening up and expanding current inventory-control programs. This approach will significantly impact the three major sources of waste resulting from improper inventory control: excess, out-of-date, and no-longer-used raw materials. For example, a manufacturer of polyvinyl chloride products reduced the quantity of out-of-date and off-specification raw materials generated by over 50 percent through inventory control. Techniques used included purchase of containerized rather than bulk materials, reduction in purchase quantities, and separation and reuse of excess materials where possible. The program took six months to implement at a negligible cost and saved $50,000 per year in raw material and waste management costs.[4]

Purchasing only the amount of raw materials needed for a production run or a set period of time is one of the keys to proper inventory control. Excess inventory often results from a purchasing department getting a "good deal" on a chemical and buying a tank-car load when only a drum is needed. The excess must be disposed of because it goes out of date before it can be used. Better application of existing inventory management procedures should help to reduce this problem and should be coupled with education programs for purchasing personnel on the problems and costs of disposing of excess materials. Additionally, the set expiration dates on materials should be evaluated, especially for stable compounds, to see if they are too short. A furniture manufacturer reduced excess inventories by having one person assigned to the job of purchasing all solvents and finishes for all divisions. Purchases were based on long-term production schedules, which in turn had been developed to fully utilize finishing materials.[5] Another company, a large paint formulator, reduced the quantity of discontinued finished product by developing a computerized procedure to search inventory at 2 plants and 27 warehouses for available stock before formulating another batch. Transportation costs for moving the finished products are small compared to the high hazardous waste disposal costs.[6]

Another approach to inventory control is to purchase the material in the proper amount and the proper size container. If large quantities of a material are used, then purchasing it in bulk will produce less waste, both in product loss and empty packaging, than if it were purchased in drums or bags. On the other hand, small containers may be better than bulk purchases if the material has a short shelf life or is not used in large amounts. Some companies are purchasing material in returnable, reusable containers, thus eliminating the generation of empty bags or containers. In some cases, raw materials such as pig-

ments and biocides can be packaged in small soluble bags which allow the material and container to be put right into the processed product.[7,8]

If surplus inventories do accumulate, steps should first be taken to use the excess material within the plant or company. If this is not successful, then the supplier should be approached to see if it will take the material back. If the supplier won't, the next step is to identify possible users or markets outside the company. Only if this fails should other management options be examined. The subject of market development is covered more fully in Sec. 3.5.

The ultimate in inventory control procedures is JIT manufacturing, since this system eliminates the existence of any inventory by directly moving raw materials from the receiving dock to the manufacturing area for immediate use. The final product is then shipped out without any intermediate storage. JIT manufacturing is a complex program to implement and cannot be used by all facilities; however, when applicable, it can reduce waste significantly. For example, using JIT techniques, the 3M Company reduced waste generation by 25 to 65 percent in its individual plants.[2]

Developing review procedures for all material purchased is another step in establishing an inventory control program. Standard procedures should require that all materials be approved prior to purchase and checked before acceptance at the facility. In the approval process all production materials should be evaluated to determine if they contain hazardous constituents, and if so, what alternative nonhazardous substitute materials are available (see Sec. 3.3.2). Also, brief evaluation procedures should be established for all incoming raw materials to avoid the acceptance of wrong, off-specification, or defective materials. This will reduce the potential for generation of off-specification products, damaged process equipment, and disposal of unusable raw materials.

Development of review procedures determination can be made either by one person with the necessary chemistry background or a committee made up of people with a variety of backgrounds. Needed information can be obtained from the Material Safety Data Sheets (MSDS) provided by the chemical supplier. If these data sheets do not contain enough information, the supplier should be contacted and asked to provide the necessary information in confidence. If the chemical supplier is unable or unwilling to provide the information, either a new supplier should be found or the materials should be chemically analyzed. Any material which has been approved can be ordered; new material must first go through the approval process. This approach fits very well with health and environmental regulations, which require chemical inventories and collection of MSDSs. Evaluation of

this information can lead to fewer chemicals being stored, used, and released, thus reducing regulatory burdens and potential liabilities. Many kinds of companies, hailing from the electronics industry to the textile industry, have established successful material review programs.[9,10,11] Material review procedures should also be applied during new-product development. Before a new product is produced, a thorough evaluation of the materials and processes used to make the product should be made. The use of hazardous materials can then be reduced as much as possible prior to beginning production.[12,13]

3.2.2 Material control

An important area commonly overlooked or not given proper attention in many manufacturing facilities is material control procedures, which includes storage of raw materials, products, and process waste and the transfer of these items within the process and around the facility. Proper material control procedures will ensure that raw materials will reach the production process without loss through spills, leaks, or contamination. It also will ensure that the material is efficiently handled and used in the production process and does not become waste. Examples of potential sources of material loss are shown

TABLE 3.2 Potential Sources of Process Material Loss

Area	Source
Loading	Leaking fill hose or fill line connections Draining of fill lines between filling Punctured, leaking, or rusting containers Leaking valves, piping, and pumps
Storage	Overfilling of tanks Improper or malfunctioning overflow alarms Punctured, leaking, or rusted containers Leaking transfer pumps, valves, and pipes Inadequate diking or open drain valve Improper material transfer procedures Lack of regular inspection Lack of training program
Process	Leaking process tanks Improperly operated and maintained process equipment Leaking valves, pipes, and pumps Overflow of process tanks; improper overflow controls Leaks and spills during material transfer Inadequate diking Open drains Equipment and tank cleaning Off-specification raw materials Off-specification products

in Table 3.2. A resin manufacturer provides an example of how proper raw-material transfer procedures can reduce waste generation. With this manufacturer it was common practice to let the residual material in the hose from the phenol delivery trucks drain into the plant's wastewater collection system after the storage tanks were filled. The unloading procedures were then changed to require the hoses to be flushed with water and the phenol-water mixture be stored in a tank for use in the production process.[14]

Material loss can be greatly reduced through improved process operation, increased maintenance, and additional employee training. Many sources of material loss, such as leaks and spills, can be easily identified and corrected. For example, a dairy plant reduced its product loss by 65 percent through an improved maintenance program.[15] Many of the techniques which can be used to reduce material loss are discussed in Sec. 3.3.1.

Another problem area which is frequently overlooked is waste handling procedures. Waste should be handled and managed like a product. Allowing a recyclable or clean waste material to be contaminated may reduce or eliminate any recovery potential. One way to improve the material control procedures is to have at least one person responsible for handling and tracking waste materials within the plant. This approach can be very cost-effective when the waste material is recoverable or has some market value. This area is discussed further in Sec. 3.5.

3.3 Production Process Modification

Improving the efficiency of a production process can significantly reduce waste generation. Use of this approach can help reduce waste at the source of generation, thus decreasing waste management liability and costs. Some of the most cost-effective reduction techniques are included in this category; many are simple and relatively inexpensive changes to production procedures. Available techniques range from eliminating leaks from process equipment to installing state-of-the-art production equipment. The waste reduction techniques in this category can be divided into improved operation and maintenance, material change, and equipment modifications. Each topic is discussed in more detail in the following sections.

3.3.1 Operational and maintenance procedures

Significant amounts of waste can be reduced through improvements in the way a production process is operated and maintained. This approach is one of the most overlooked of all waste reduction areas be-

cause many wasteful operational practices have gone on so long they have become standard operating procedures. Also, in many cases, maintenance is so busy correcting current problems that preventive maintenance is overlooked until it is too late. Improvements in operation and maintenance usually are relatively simple and cost-effective. Most of the techniques are not new or unknown. However, a good deal of information on the source and cause of the waste generation must be known before effective measures can be developed.

A certain dairy processing facility provides a good example of significant waste reduction through improved operation and maintenance procedures. A milk loss prevention program was instituted which included employee training on proper operations, causes of product loss, and impact of waste generation; increased maintenance, including correction of current leaking equipment; better tracking of product losses; and development of improved operational techniques. This program saved the company $288,000 per year and has resulted in a significant reduction in the organic content of the wastewater. All this was obtained without any capital costs.[15,16]

Operational procedures A wide range of methods are available to operate a production process at peak efficiency. These methods are neither new nor unknown and are usually inexpensive to institute, as little or no capital cost is necessary. For example, a manufacturer of plumbing fixtures changed the concentration of chrome in its electroplating baths to the low end of the recommended operating range. By reducing the chrome concentration from 3700 mg/liter to 3350 mg/liter the amount of chrome which had to be treated was reduced by 9 percent without affecting product quality. This not only saved raw material and treatment chemicals, but it also reduced wastewater treatment sludge generation.[17]

Improved operation procedures are quite simply methods which make optimum use of the raw materials used in the production process. Some examples are shown in Table 3.3. Most production processes, no matter how long they have been in operation or how well they are run, can be operated more efficiently. Many sources of waste generation become overlooked because "that is just the way the process works." Additionally, some process steps may in fact be unnecessary, and eliminating them will reduce waste generation. For example, a paint manufacturer found that instead of using a series of coarse to fine filters for grit removal, only the fine filter was necessary. As a result of this change to using only one filter, the generation of spent filter cartridges was reduced by 50 percent.[6] Another company discovered that standard operating procedure was to degrease all parts coming into the facility and then re-oil those that did not require further

TABLE 3.3 Examples of Operational Changes to Reduce Waste Generation

Reduce raw material and product loss due to leaks, spills, drag-out, and off-specification process solution.
Schedule production to reduce equipment cleaning. For example, formulate light to dark paint so the vats do not have to be cleaned out between batches.
Inspect parts before they are processed to reduce number of rejects.
Consolidate types of equipment or chemicals to reduce quantity and variety of waste.
Improve cleaning procedures to reduce generation of dilute mixed waste with methods such as using dry cleanup techniques, using mechanical wall wipers or squeegees, and using "pigs" or compressed gas to clean pipes and increasing drain time.
Segregate wastes to increase recoverability.
Optimize operational parameters (such as temperature, pressure, reaction time, concentration, and chemicals) to reduce by-product or waste generation.
Develop employee training procedures on waste reduction.
Evaluate the need for each operational step and eliminate steps that are unnecessary.
Collect spilled or leaked material for reuse.

SOURCE: From Refs. 4, 6, 7, 19, and 20.

coating and that cleaning only those parts which needed further processing would reduce waste solvent generation.[18] Thus, asking why a process step has to be done will help identify reduction possibilities.

These approaches can be used by all sizes and types of facilities, even by well-designed and well-operated complex operations. For example, an organic chemical company, during a comprehensive process evaluation, found three significant sources of isobutylene emissions to the atmosphere. Laboratory scale tests found that changes in the reaction conditions (temperature, residence time, and concentration) would almost eliminate isobutylene emission while also increasing product generation. For example, for one reaction step emissions were reduced 99 percent, primary product yield was increased from 94.5 to 99.7 percent, and batch cycle time was reduced by half. The total saving from the operational changes at all these reaction steps was $500,000 per year, with a total capital cost of $80,000. Additionally, the need for air pollution control equipment was eliminated.[20]

Once proper operating procedures have been established they must be fully documented and made part of the employee training program. A comprehensive training program is a key element of any effective waste reduction program. For example, a dairy reduced waste by 14 percent and a semiconductor manufacturer reduced waste by 40 percent through use of such training programs.[18,22] For a program to be effective, all levels of personnel should be included, from the line operator to the corporate executive officer. The goal of any program is to

make the employee aware of waste generation, its impact on the company and the environment, and ways it can be reduced. Top level managers have to be made aware of the costs, problems, and liabilities of waste management, and the economic benefits of waste reduction. Line managers must understand the effect of their process line on waste generation in order to focus on how waste can be reduced, how to educate and motivate their employees. The majority of the training program should be directed at the line operators. Some possible program elements are shown in Table 3.4. The training program should emphasize management's commitment to waste reduction, the beneficial impact of reduction on job security, and the improvements reduction will make to the local environment. All employees should attend refresher sessions on a regular basis. All new workers should undergo the training, which could be done as part of an established worker right-to-know training program for new employees.

Companies have taken a number of different approaches to waste reduction training. One facility has developed a training video to introduce waste reduction to the line operator with simple written waste reduction procedures for each line operation. Also at this facility, training and written material were developed for line supervisors and all levels of management.[18] A furniture manufacturer took a rather unique approach. Working closely with the line operator, video equipment was used to record the operator's spray technique. The tape was later reviewed by the operator and training personnel to identify problem areas and provide corrective procedures. The operator was videotaped again later so that the operator could see the improvements. The company estimates that coating use and the associated waste gen-

TABLE 3.4 Elements in a Waste Reduction Training Program

1. Explain the need for waste reduction and emphasize benefits to employee and community.
2. Explain the direct effect that an employee can have on improved work and living environment.
3. Express management's commitment to waste reduction.
4. Explain waste management terminology in simple terms.
5. Present general overview of environmental regulations which impact the facility.
6. Examine improved operational practices for reducing waste generation. Illustrate good and poor operating practices utilizing slides or video. Use positive language, e.g., "this is a better way of doing things," instead of "this is what you have to do."
7. Solicit ideas for waste reduction methods and explore possible solutions to identified problems.

SOURCE: From Ref. 23.

eration costs were reduced by about 10 percent. This represented a savings of about $60,000 per year in coating material costs alone. Savings were also realized through reduced waste from spray booth cleanout and reduced air emissions.[3]

Maintenance programs One company stated that one-fourth to one-half of its excess waste load was due to poor maintenance.[24] A strict maintenance program which stresses corrective *and* preventive maintenance can reduce waste generation caused by equipment failure. Such a program can help spot potential sources of release and correct a problem before any material is lost. A good maintenance program is so important because the benefits resulting from the best waste reduction program can be wiped out by just one process leak or equipment malfunction.

A maintenance program can include maintenance cost tracking and preventive maintenance scheduling and monitoring. To be effective, a maintenance program should be developed and followed for each operational step in a production process, with special attention to potential problem points. A strict schedule and accurate records on all maintenance activities should be maintained. The type of information which should be collected and updated regularly in order to establish a preventive maintenance program is listed below:[25]

- A list of all plant equipment and location
- Operating time for each item or area
- Which items are critical to the process(es)
- Problem equipment
- Previous maintenance history
- Vendor maintenance manuals
- A data base of equipment repair histories

Computer-based maintenance scheduling and tracking programs are available from a variety of vendors. A comprehensive program can also include predictive maintenance. This approach provides the means to schedule repairs or replacement of equipment based on actual condition of the machinery. A number of nondestructive testing technologies are available for making the necessary evaluations for this approach.[26]

Maintenance procedures themselves produce waste, such as process materials, rags, scrap parts, oils, and cleanup residue. These wastes, too, can be reduced by using standard waste reduction techniques such as revised operational procedures, equipment modification, source

segregation, and recovery. For example, before a filter is replaced, all process material should be drained from the housing, either under gravity or pressure, and collected for reuse.[27]

3.3.2 Material change

Hazardous material used in either a product formulation or in a production process may be replaced with a less hazardous or nonhazardous material. Reformulating a product to contain less hazardous material should reduce the amount of hazardous waste generated during both the product's formulation and its end use. Using a less hazardous material in a production process will generally reduce the amount of hazardous waste produced. Some examples of material change to reduce waste generation are given in Table 3.5.

Product reformulation is one of the more difficult waste reduction techniques, yet it can be very effective. As more manufacturers implement inventory management programs, pressure will increase on chemical supply companies to produce products with lower quantities of hazardous materials. Due to the proprietary nature of product formulations, specific examples of product reformulation are scarce. General examples include eliminating pigments containing heavy metals from ink, dyes, and paint formulations; replacing chlorinated solvents

TABLE 3.5 Examples of Waste Reduction Through Material Change

Industry	Technique
Household appliances	Eliminate cleaning step by selecting lubricant compatible with next process step.[28*]
Printing	Substitute water-based ink for solvent-based ink.[29]
Textiles	Reduce phosphorus in wastewater by reducing use of phosphate-containing chemicals.[30] Use ultraviolet light instead of biocides in cooling towers.[35]
Air conditioners	Replace solvent-containing adhesives with water-based products.[31]
Electronic components	Replace water-based film-developing system with a dry system.[9]
Aerospace	Replace cyanide cadmium-plating bath with a noncyanide bath.[32]
Ink manufacture	Remove cadmium from product.[33]
Plumbing fixtures	Replace hexavalent chrome-plating bath with a low-concentration trivalent chrome-plating bath.[34]
Pharmaceuticals	Replace solvent-based tablet-coating process with a water-based process.[36]

*Superior numbers refer to sources in Reference list at end of chapter.

with nonchlorinated solvents or water in cleaning products; replacing phenolic biocides with other less toxic compounds in metalworking fluids; and developing new paint, ink, and adhesive formulations based on water rather than organic solvents. The applicability of this technique will be very product-specific, but with the ever-increasing cost and liability associated with waste management, it is a very important waste reduction and business strategy.

Hazardous chemicals used in the production process can also be replaced with less hazardous or nonhazardous materials. Changes can range from using purer raw materials to replacing solvents with water-based products, which is a very widely used waste reduction technique that is applicable to many industries. Many of these changes involved switching from a solvent to a water-based process solution. For example a diesel engine remanufacturing facility switched from cleaning solvents and oil-based metalworking fluids to water-based products. This change reduced their coolant and cleaning costs by about 40 percent. Additionally, the company was able to eliminate a cleaning step, and machine filters lasted twice as long, thus reducing material and labor costs.[37] A material change may also allow the elimination of a process step. A manufacturer of home appliances used this approach to replace an alkaline degreasing step used in a stamping process. A water-based degreaser had replaced a solvent degreaser using 1,1,1-trichloroethane. However, the alkaline degreaser residue on the parts caused deterioration of the stamping dies. The cleaning step was then eliminated by selecting a new lubricant which was noncorrosive to the stamping dies. Additionally, this lubricant did not have to be removed before the next process step, annealing, because it would be burned off in the annealing ovens.[28]

This last example points out one major source of possible problems with material changes, i.e., an adverse effect on the production process, product quality, or waste generation. This possibility can be overcome by carefully evaluating possible impacts of the proposed change on worker health, product quality, process operation, inventory, production costs, and waste management. Conducting pilot-scale tests, trial runs, and phasing in the change over time will help eliminate some potential problems.

One important area which is sometimes overlooked in making a material change is its impact on the total wastestream. Switching from a solvent-based to a water-based product can increase wastewater volumes and concentrations, which could adversely affect the current wastewater treatment system, cause effluent limits to be exceeded, and possibly increase wastewater treatment sludge production. Thus, before any change is made, its impact on all emissions must be evaluated. For example, a small metal fabricator switching from a solvent-

based to a water-based product can significantly increase the organic and oil concentration in the wastewater. This increase may require the plant to install new or additional wastewater treatment capacity and/or pay significantly increased sewer use fees.

Reducing or eliminating hazardous materials from the production process can decrease not only hazardous waste generation, but also the quantity of hazardous materials in air emissions and wastewater effluents. This can, if properly evaluated, reduce the capital investment in treatment systems needed to meet pollution discharge limits. For example, a producer of gift-wrapping paper switched from solvent-based to water-based inks. This change saved the company $35,000 per year on hazardous waste management costs. Furthermore, it saved the company from having to install an air pollution control system, to control volatile organic carbon emissions, which would have cost several million dollars.[31]

3.3.3 Process equipment modification

Waste generation may be reduced by installing more efficient process equipment or modifying existing equipment to take advantage of better production techniques. New or updated equipment can use process materials more efficiently, producing less waste. Additionally, higher-efficiency systems may reduce the number of rejected or off-specification products, thereby reducing the amount of material which has to be reworked or disposed of. The use of more efficient equipment or processes can pay for itself through higher productivity, reduced raw material costs, and reduced waste management costs. The necessary capital investment can usually be justified by the increased production rates, and reduced waste management costs provide an added bonus.[33,9] Some examples of process modifications are given in Table 3.6.

Modifying existing process equipment can be a very cost-effective method for reducing waste generation. In many cases the modifications can just be relatively simple and inexpensive changes in the way the materials are handled within the process to ensure that they are not wasted or lost. This can be as easy as redesigning parts racks to reduce drag-out in electroplating operations, installing better seals on process equipment to eliminate leakage, or installing drip pans under equipment to collect leaking process material for reuse.[38,18] In many cases, process modifications and improved operational procedures are used together to reduce waste. One chemical company reduced the waste from a sump in a production area from 31,750 kg/year to 1360 kg/year by installing a sight glass, using better pump scales, and purchasing a broom.[39] Modifying equipment to improve operational effi-

TABLE 3.6 Examples of Production Process Modifications for Waste Reduction

Process step	Technique
Chemical reaction	Optimize reaction variables and improve process controls. Optimize reactant-addition method. Eliminate use of toxic catalysts. Improve reactor design.
Filtration and washing	Eliminate or reduce use of filter aids and disposable filters. Drain filter before opening. Use countercurrent washing. Recycle spent washwater. Maximize sludge dewatering.
Parts cleaning	Enclose all solvent cleaning units. Use refrigerated freeboard on vapor degreaser units. Improve parts draining before and after cleaning. Use mechanical cleaning devices. Use plastic-bead blasting.
Surface finishing	Prolong process bath life by removing contaminants. Redesign part racks to reduce drag-out. Reuse rinse water. Install spray or fog nozzle rinse systems. Properly design and operate all rinse tanks. Install drag-out recovery tanks. Install rinse water flow control valves. Install drip racks and drainboards.
Surface coating	Use airless air-assisted spray guns. Use electrostatic spray-coating system. Control coating viscosity with heat units. Use high-solids coatings. Use powder coating systems.
Equipment cleaning	Use high-pressure rinse system. Use mechanical wipers. Use countercurrent rinse sequence. Reuse spent rinse water. Use "pigs" to clean lines. Use compressed gas to blow out lines.
Spills and leaks	Use bellow-sealed valves. Install spill basins or dikes. Use sealless pumps. Maximize use of welded pipe joints. Install splash guards and drip boards. Install overflow control devices.

SOURCE: From Refs. 18, 21, and 40–44.

ciency requires a thorough understanding of both the production process and wastestream generation. In many cases it is best to phase in the required process modifications over a period of time to reduce any potential effects on the whole production process and to evaluate its impact on the wastestream. As discussed before, the impact on all wastestreams must be evaluated.

Installing new, more efficient equipment and, in some cases, modifying current equipment will require capital investment in equipment, facility modifications, and employee training. The extent of the investment will vary over a large range depending on the type of equipment used. Replacing a solvent vapor degreaser with a household dishwasher to clean circuit boards may cost only several hundred dollars, while replacing a spray coating operation with a powder coating system may cost hundreds of thousands of dollars and require new facilities and extensive employee training. What they have in common is that they both will pay back the investment costs.[18]

Examples of new, more efficient process equipment are numerous in the literature, but little is usually said about reduced waste generation and management costs. The following example shows what one company saved when new process equipment was installed. When an automated metal electroplating system was installed to replace the manual operation, annual productivity increased and system downtime decreased from 8 percent to 4 percent. Chemical consumption decreased 25 percent, resulting in an annual reduction of $8000 per year in raw material costs. Water costs were reduced by $1100 per year, and plating wastes, including acids, caustic, and oils, decreased from 204 kg/day to 163 kg/day. Treatment costs for the process water used in the plating operation were reduced by 25 percent. Annual personnel and maintenance cost savings attributable to the new system are $35,000 per year. The automated system has also eliminated worker exposure to acids and caustics, which had been required with the previous manual operation.[17]

As discussed earlier in this section, the use of more efficient process equipment can also mean changing to less hazardous process materials. For example, one furniture company switched from a manual staining operation using solvent-based materials to an automatic staining system using water-based stains. The new process reduced the time required to stain a pallet of parts by 95 percent and reduced raw material usage by 20 percent. The savings in labor alone paid for the new staining system in just three months.[3]

One important factor which is sometimes overlooked in evaluating the cost-effectiveness of equipment modifications is the cost associated with reworking or disposing of off-specification products. This can be very expensive, not only in terms of labor and materials, but also in

waste management costs. In many manufacturing operations which involve coating a product, such as electroplating or painting, chemicals are used to strip off the coating from rejected products so that they can be recoated. These chemicals, which can include acids, caustics, cyanides, and chlorinated solvents, often are hazardous wastes which must be properly managed. By reducing the quantity of parts which must be reworked, the quantity of waste can be reduced.

3.4 Volume Reduction

Volume reduction includes techniques to separate hazardous wastes and recoverable wastes from the total wastestream. These techniques are usually used to increase recoverability, reduce the volume and thus the disposal costs, or increase management options. The available techniques used range from simple segregation of wastes at the source to complex concentration technology, as shown in Table 3.7. They are applicable to all types of wastestreams. These techniques can be divided into two general areas: source segregation and waste concentration. Only those methods which are actual waste reduction techniques will be discussed in this section.

3.4.1 Source segregation

Segregation of wastes is in many cases a simple and economical technique for waste reduction. For example, by segregating wastes at the

TABLE 3.7 Examples of Waste Reduction Through Volume Reduction

Industry	Technique
X-ray film	Segregate polyester film scrap from other production waste and recycle.[24*]
Resins	Collect waste resin and reuse in next batch.[62]
Printed circuit boards	Use filter press to dewater sludge to 60% solids and sell sludge for metal recovery.[17]
Pesticide formulation	Use separate bag houses at each process line and recycle collected dust into product.[45]
Research laboratory	Segregate chlorinated and nonchlorinated solvents to allow off-site recovery.[17]
Aircraft components	Use ultrafiltration to remove recoverable oil from spent coolants.[13]
Paint formulation	Segregate and reuse tank-cleaning solvents in paint formulations.[23]
Furniture	Segregate and reuse solvents used to flush spray-coating lines and pumps as coating thinner.[33]

*Superior numbers refer to sources in Reference list at end of chapter.

source of generation and handling the hazardous and nonhazardous wastes separately, waste volume and thus management costs can be reduced. Additionally, the uncontaminated or undiluted wastes may be reusable in the production process or may be sent off site for recovery.

The segregation technique is applicable to a wide variety of wastestreams and industries and usually involves simple changes in operational procedures. For example, in metal-finishing facilities, wastes containing different types of metals can be treated separately so that the metal values in the sludge can be recovered. Keeping spent solvents or waste oils segregated from other solid or liquid waste may allow them to be recycled. Wastewater containing toxic material should be kept separate from uncontaminated process water to reduce the overall volume of water which must be treated.

A commonly used waste segregation technique is to collect and store washwater or solvents used to clean process equipment (such as tanks, pipes, pumps, or printing presses) for reuse in the production process. This technique is used by paint, ink, and chemical formulators, as well as by printers and metal fabricators. For example, a printing firm segregates and collects toluene used for press and roller cleanup operations. By segregating the used toluene by color and type of ink contaminant, it can be reused later for thinning the same type and color of ink. The firm now recovers 100 percent of the waste toluene, totally eliminating a hazardous wastestream.[17]

Another way to apply the segregation technique is to collect and reuse back in the product dust and excess materials generated during the manufacturing process. This technique is used by one pesticide formulator to reduce the volume of hazardous waste it generates. The firm collects the dust generated during the formulation process in a separate bag house for each process line. The collected dust is then reused in the product as an inert filler. This has eliminated the generation of 20,412 kg/year of waste, saving the company $9000 in disposal costs and $2000 in raw material costs. These savings paid for the necessary equipment in less than a year.[17]

3.4.2 Concentration

Various techniques are available to reduce the volume of a waste through physical treatment. Such techniques usually remove a portion of a waste, such as water. For example, concentration techniques are commonly used to dewater wastewater treatment sludges and reduce the volume by as much as 90 percent. Available concentration methods include gravity and vacuum filtration, evaporation, ultrafiltration, reverse osmosis, freeze vaporization, filter press, heat dry-

ing, and compaction. Many of these actually are recovery techniques and will be discussed further in the next section. Concentration techniques are available for all types of wastestreams and are used by a wide range of industries.

Unless a material can be recycled, just concentrating a waste so more waste can fit into a drum is not waste reduction. In some cases concentration of a wastestream may also increase the likelihood that the material can be reused or recycled. For example, filter presses or sludge driers can increase the concentration of metals in electroplating wastewater treatment sludge to such a level that they become valuable raw material for metal smelters. A printed circuit board manufacturer dewaters its sludge using a filter press to 60 percent solids. The company receives $7200 per year through the sale of the dewatered sludge for copper reclamation.[17]

3.5 Recovery

Recovering wastes can provide a very cost-effective waste management alternative. This technique can help eliminate waste disposal costs, reduce raw material costs, and possibly provide income from a salable waste. Recovery of wastes is a widely used practice in many manufacturing processes and can be done on site or at an off-site facility. It has been used for centuries to increase productivity and profitability. In fact, the organic chemical industry in the mid-1800s produced aniline dyes which were made from coal gasification plant waste.[46] Current production facilities have the potential to increase greatly the recycling of waste materials based on present regulatory impacts, increased waste management costs, and new waste recovery technologies and approaches.

Waste recovery should only be considered after all other waste reduction options have been instituted. Actually reducing the amount of waste generated at the source will usually be more cost-effective than recycling. In many cases this is because a waste is lost raw material or product which requires time and money to manage and recover. Also, simply generating and handling a waste produces a range of regulatory, health, and environmental liabilities.

All of the previously discussed waste reduction techniques can be used in conjunction with recovery to produce a cost-effective waste management program. One company, a producer of breaded foods, used a variety of waste reduction techniques to significantly reduce waste generation. A management and employee training program on waste reduction techniques and their impact on company profits was instituted. Improved operation and maintenance procedures were instituted, including using dry cleanup for spills and equipment, install-

ing or modifying drip trays under process equipment to better collect lost process material, and developing better systems for collecting and handling waste materials so they could be sold to a recovery firm. These, plus a number of reduction techniques, decreased water usage by about 30 percent, eliminated the landfilling of waste solids, reduced the organic load of the wastewater by almost 80 percent, and allowed the company to sell 2,359,000 kg/year of solids to recovery firms.[47]

The effective use of recovery will depend on the segregation of the recoverable waste from other process wastes or extraneous material. This segregation ensures that the waste is uncontaminated and the concentration of recoverable material is maximized. The waste, then, must be handled like a product. Many of the inventory control techniques discussed in Sec. 3.1 can be applied to waste materials. Some companies have assigned responsibility for the handling, collection, and scheduling of recovery of waste material to one individual.[13,47,48] This helps ensure that the maximum value of the waste can be recovered.

3.5.1 On-site recovery

In most cases the best place to recover process wastes is within the production facility. Wastes which are simply contaminated versions of the process raw materials are good candidates for in-plant recycling. Such recovery can significantly reduce raw material purchases and waste disposal costs. Waste can be most efficiently recovered at the point of generation, because the possibility of contamination with other waste materials is reduced, as is the risk involved with handling and transporting waste materials. See Sec. 3.4 for information on segregation techniques. Some examples of on-site waste recovery are shown in Table 3.8.

Some wastestreams can be reused directly in the original production process as raw material. This easy reuse is usually accomplished when the waste material is lightly contaminated or is excess raw material. Examples include the cleaning waste from printers, coaters, and chemical or product formulators; electroplating drag-out solutions; process solutions from filter changes; and dust collector residue from pesticide formulators.[21,27,38,45] Lightly contaminated waste can sometimes be reused in operations not requiring high-purity materials. For example, spent high-purity solvents generated during the production of microelectronics can be reused in less critical metal-degreasing operations, or a caustic waste material can be reused to treat an acid wastestream.

Some waste may have to undergo some type of purification before it

TABLE 3.8 Examples of Waste Reduction Through Recovery and Reuse

Industry	Technique
Printing	Use a vapor-recovery system to recover solvents.[17]*
Photographic processing	Recover silver, fixer, and bleach solutions.[17]
Metal fabrication	Recover synthetic cutting fluid using a centrifuge system.[33]
Mirror manufacturing	Recover spent xylene using a batch-distillation system.[33]
Printed circuit boards	Use electrolytic recovery system to recover copper and tin/lead from process wastewater.[49]
Tape measures	Recover nickel-plating solution using an ion-exchange unit.[40]
Medical instruments	Use reverse-osmosis system to recover nickel-plating solution.[40]
Power tools	Recover alkaline degreasing baths using an ultrafiltration system.[17]
Textiles	Use ultrafiltration system to recover dye stuffs from wastewater.[50]
Hosiery	Reconstitute and reuse spent dye baths.[50]
Food processing	Send all solids off site for by-product recovery.[47]
Wastewater treatment	Reuse waste caustic solids to treat acid wastestream.[51]
Pickles	Transfer waste brine pickle solution to a textile plant as a replacement for virgin acetic acid.[52]
Chemicals	Use spent electrolyte from one division as raw material in another.[53] Purify hydrochloric acid in wastestream and sell as a product.[54]
Industrial and consumer products	Segregate and sell office paper, corrugated cardboard, paper trimming, and rejected paper products.[2]
Aluminum die-caster	Sell waste fumed amorphous silica for use in concrete.[55]

*Superior numbers refer to sources in Reference list at end of chapter.

can be reused. A number of physical and chemical techniques available on the market can be used to reclaim a waste material, as shown in Table 3.8. These techniques range from simple filtration to state-of-the-art techniques such as freeze crystallization.[56,57] The method of choice will depend on the physical and chemical characteristics of the wastestream recovery economics, as well as on operational requirements. For a number of wastestreams there are economical small

modular recovery units available. Some of the materials commonly recycled by these modular units are spent solvents, electroplating process waste, and spent metalworking fluids.

A certain manufacturer of shopping carts provides a good example of on-site recovery methods and cost savings. The company installed three atmospheric evaporators on the nickel- and chrome-plating lines. These units evaporate water from the plating bath, allowing all rinse water to be returned and thus recovering all dragged-out nickel and chrome plating solutions. With the start-up of the evaporators, raw chemical use declined dramatically: purchases of 1800 kg of nickel sulfate per month have declined to zero; chromic acid purchases have declined by 75 percent, from 900 kg/month to 200 kg/month; and sodium bisulfite used in the waste treatment process for chromic acid has declined from 1800 kg/month to 200 kg/month. Annual savings are projected to be $112,500. The cost of the three atmospheric evaporators was $60,500, with a payback period of only seven months and an annual savings of $145,000.[9]

Most on-site recovery systems will generate some type of residue (i.e., contaminants removed from the recovered material). This residue can either be processed for further recovery or properly disposed of. For example, a solvent distillation system will usually recover only 90 percent of the input spent solvent for reuse. The residues or distillation bottoms are a hazardous waste and as such must be managed in an approved manner. The economic evaluations of any recovery technique must include the management of these residues.

3.5.2 Off-site recovery

Wastes may be recovered at an off-site facility when (1) the equipment is not available to recover on site, (2) not enough waste is generated to make an in-plant system cost-effective, or (3) the recovered material cannot be reused in the production process. Off-site recovery usually entails recovering a valuable portion of the waste through chemical or physical processes or directly using the waste as a substitute for virgin material. Some materials which are commonly reprocessed off site are oils, solvents, electroplating sludges and process baths, lead-acid batteries, scrap metal, food-processing waste, plastic scrap, and cardboard. Wastes directly used are usually chemically or physically specific for a select purpose (i.e., have the same physical or chemical properties as the raw materials they replace) and can range from concentrated acids to chemical by-product streams. This alternative is described further in Sec. 3.2.1. Some examples of materials which have been recovered off site are shown on Table 3.8.

For wastes regulated under the Resource Conservation and Recov-

ery Act (RCRA) there are regulatory barriers to some forms of off-site recovery. Additionally, for hazardous waste the generator is liable for the waste material handled at a recovery facility and for any residue produced. This responsibility may pose possible long-term liability problems. Check with state and federal regulatory agencies for the impact of the regulation on any off-site recovery activity.

The cost of off-site recycling will depend on the purity of the waste and the market for the waste or recovered material. Some materials may be salable, while others may require a fee to be paid for disposal. The markets for some wastes, such as scrap metals and waste oils, are very volatile, and a waste material which has a value one day may have none the next.

For some process materials, such as solvents, the supplier may provide services to pick up the material, recover it, and return it for reuse. Known as *tolling*, this vendor service provides a good way to reduce disposal and raw material costs because the reclaimed material is usually cheaper than virgin material. This arrangement is widely used for metal-cleaning operations, such as machine shops or automotive repair stations, that use cold cleaners. In these operations, a solvent cleaner is provided for use in a leased parts-washing sink. On a regular schedule the supplier brings in fresh solvent and removes the spent solvent for recovery. This procedure is much cheaper for a small company than if it were to dispose of the solvent itself; however, the generator is still liable for proper recovery of the solvent and management of the distillation residues.

In some situations a waste may be transferred to another company for use as a raw material in the other company's manufacturing process. This exchange can be economically advantageous to both firms as it will reduce the waste disposal costs of the generator and reduce the raw material costs of the user. This upgrade of a waste into a product requires a strong commitment from the generator to find markets for the waste material. In some cases the production process or the waste may have to undergo some modification in order to make a more salable product.

A product-development approach can be used to identify and develop markets for a waste material. An example of the ordered steps in such an approach follows:[53,58]

- Determine waste composition and generation rate.
- Evaluate on-site and in-company uses.
- Evaluate off-site uses and locate potential customers and markets.
- Identify any processing required to meet product specifications.
- Evaluate potential customers.

- Negotiate recycle agreement.

The marketing effort is usually undertaken by individuals in a company's sales or purchasing department, with support from engineering and technical staff. Some larger companies have dedicated groups for just marketing waste materials and surplus materials. Markets for the waste can be identified through advertising, contacts with trade associations, waste exchanges, industrial contacts, brokers, and a number of literature sources.[58,59]

Regional waste exchanges have been set up by a number of states to act as information clearinghouses of wastes that are available and wastes that are sought. A waste exchange can help identify possible markets for a material. The service usually offered is a listing in a catalog or computer data base form of wastes available from generators and sought by users. This information is distributed throughout a specific geographic area. A company interested in a waste contacts the waste exchange, which forwards the inquiry to the listing company. Usually, actual negotiations and material transfers are handled directly by the companies. A current listing of waste exchanges is given in Table 3.9.

Before a company looks outside itself for markets, internal uses should be evaluated. Probably some of the most cost-effective recycling efforts are made within a company because the waste replaces material that otherwise would have to be purchased or produced. It may be possible to use the material directly, or the material may have to undergo some further processing, as discussed below. One chemical manufacturer had the distillation bottoms from a production process refined at an outside custom processor for use as raw material at another facility, saving the company over $1 million per year in raw material and disposal costs.[53] One approach for excess off-specification material is to set up a corporate waste exchange using a newsletter or even a computer data base system to help identify users for waste material. This approach has been taken by a number of companies.[12,27,59] For example, one large corporation purchasing department lists surplus materials at all plant locations in a computer data system. Before any materials are purchased for a given plant, the purchasing department checks to determine if they are available at another location.[27]

Some wastes may have to be upgraded before a market can be found for them. This upgrading can be in the form of purification, concentration, particle sizing, or other processes. The material itself can undergo processing, or else the production process can be modified to produce a higher-quality wastestream. For example, a circuit board manufacturer found that in order to market its copper-containing wastewater treatment sludge, the sludge must have a low iron concen-

TABLE 3.9 North American Waste Exchanges

Alberta Waste Materials Exchange 4th Floor Terrace Plaza 4445 Calgary Trail South Edmonton, Alberta Canada T6H 5R7	Industrial Waste Information Exchange New Jersey Chamber of Commerce 5 Commerce Street Newark, NJ 07102
California Waste Exchange Department of Health Services Toxic Substances Control Division 714 P Street Sacramento, CA 95814	Manitoba Waste Exchange c/o Biomass Energy Institute 1329 Niakwa Road Winnipeg, Manitoba Canada R2J 3T4
Canadian Waste Materials Exchange Ontario Research Foundation Sheridan Park Research Community Mississauga, Ontario Canada L5K 1B3	Montana Industrial Waste Exchange Montana Chamber of Commerce P.O. Box 1730 Helena, MT 59624
Great Lakes Regional Waste Exchange 470 Market St., S.W., Suite 100A Grand Rapids, MI 49503	Northeast Industrial Waste Exchange 90 Presidential Plaza, Suite 122 Syracuse, NY 13202
Indiana Waste Exchange Environmental Quality Control 1220 Waterway Boulevard P.O. Box 1220 Indianapolis, IN 46206	Southeast Waste Exchange Urban Institute UNCC Station Charlotte, NC 28223
Industrial Material Exchange Service P.O. Box 19276 Springfield, IL 62794-9276	Southern Waste Information Exchange Institute of Science and Public Affairs Florida State University P.O. Box 6487 Tallahassee, FL 32313

SOURCE: From Ref. 60.

tration and be high in solids and copper concentration. An effort was undertaken to modify the wastewater treatment process so that iron-containing treatment chemicals were not used. Additionally, the sludge was dewatered using a filter press to 50 percent solids. This dewatering increased the copper concentration to 25 to 35 percent by weight, and a market for the material with a copper smelter was found. This effort, along with finding uses for several other waste-streams, now allows the company to market over 90 percent of the hazardous waste it generates.[61]

3.6 Summary

As has been shown, a wide range of waste reduction techniques currently exist and are available for most manufacturing steps. However, technology alone will not reduce waste generation. Only a comprehen-

sive waste reduction program will be successful. Such a program should include management commitment, data collection, cost-effective technology selection and implementation, employee training and involvement, and program monitoring. The foundation of any successful program is the evaluation of what wastes are generated and why they are produced. Based on this information, a range of reduction techniques can then be identified and evaluated, and the cost-effective ones implemented.

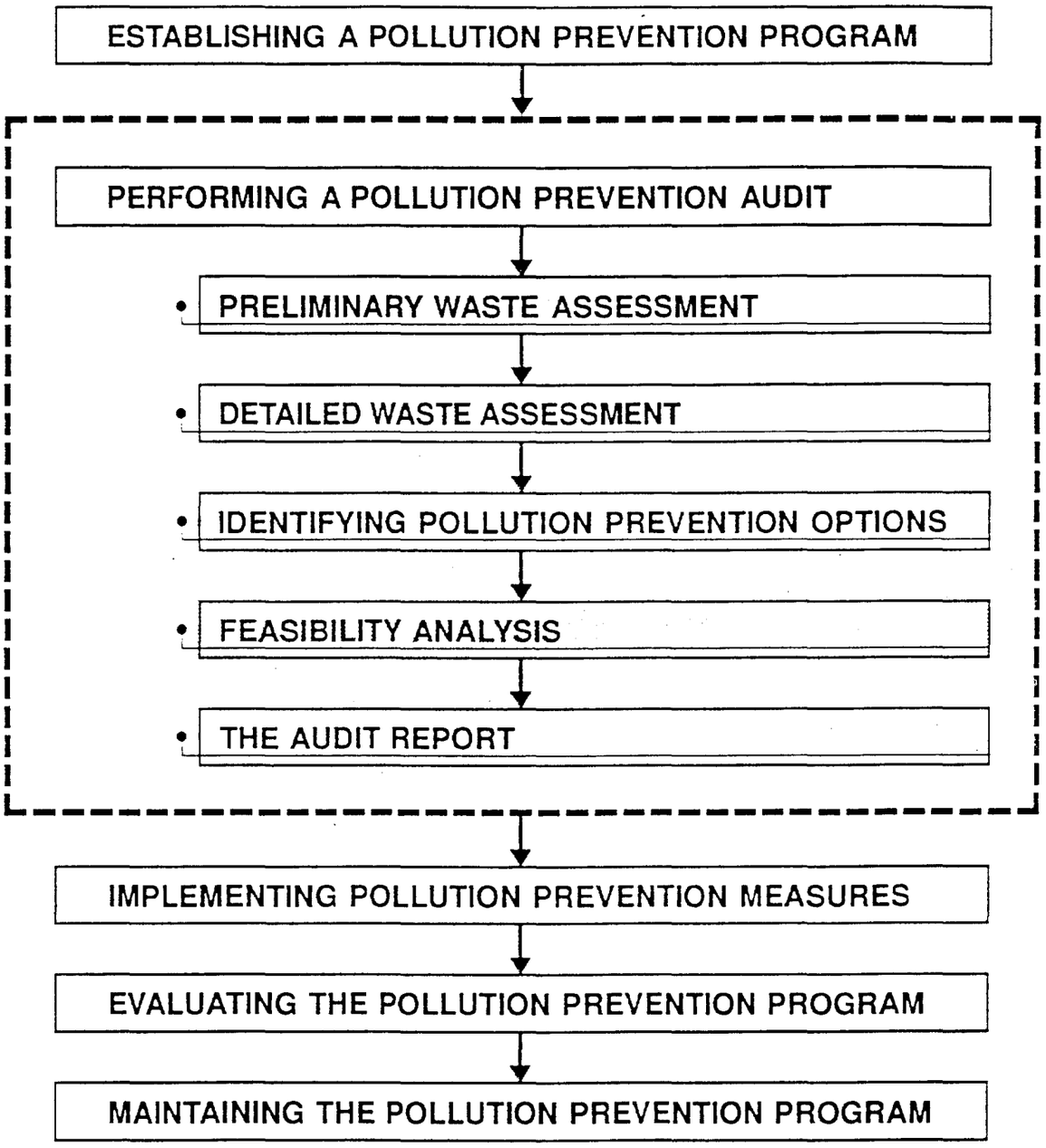
Sources of specific information on waste reduction techniques are available from a number of places. The best source, however, is discussion with the process operators, who in most cases can identify operations and equipment problems which generate waste. Additional information may be obtained from trade associations and trade journals, as well as government research reports, regulatory agencies, and technical assistance groups.

Industrial trade associations can provide the most detailed and current technical information. Many associations have staff experts with extensive knowledge and experience in waste management. A list of trade associations can be found in Ref. 62. Trade publications are another very good source of information. Many journals contain articles on case studies, current research, vendor information, and suggestions from industrial experts.

Other sources of technical information are federal and state regulatory agencies and technical assistance programs. The U.S. Environmental Protection Agency (U.S. EPA) has established an Office of Pollution Prevention to help promote waste reduction efforts by the regulated community. These efforts include research, education, and technical information. A number of states have established waste reduction technical assistance programs. The level of assistance offered by these programs varies, and the programs may include on-site technical assistance, access to information data base and documents, workshops, referral services, research, and matching grant programs. Current programs are discussed in Chap. 12. Check with your respective state environmental agencies to find out if such a program is available in your locality.

In the final analysis, waste reduction depends on looking at waste in a different way, not as something that inevitably must be treated and disposed of, but for what it really is—a loss of valuable process materials, the reduction of which can have significant economic benefits. One corporate executive summarized it all when he stated that waste is a specialty product for which a market has not yet been found.[63]

FEASIBILITY ANALYSIS


ESTABLISHING A POLLUTION PREVENTION PROGRAM
PERFORMING A POLLUTION PREVENTION AUDIT
• PRELIMINARY WASTE ASSESSMENT
• DETAILED WASTE ASSESSMENT
• IDENTIFYING POLLUTION PREVENTION OPTIONS
• FEASIBILITY ANALYSIS
• THE AUDIT REPORT
IMPLEMENTING POLLUTION PREVENTION MEASURES
EVALUATING THE POLLUTION PREVENTION PROGRAM
MAINTAINING THE POLLUTION PREVENTION PROGRAM

FEASIBILITY ANALYSIS

PURPOSE : Apply a framework for evaluating and selecting Pollution Prevention options considering all applicable requirements and limitations.

- Environmental evaluation
- Technical evaluation
- Economic evaluation

FEASIBILITY ANALYSIS

ENVIRONMENTAL EVALUATION

- Will the option effectively reduce waste at the source ?
- Are there cross-media effects ? (e.g. does reducing emissions lead to liquid waste ?)
- Is toxicity, degradability, or treatability of the waste changed ?
- Are more non-renewable resources used ?
- Is more energy used ?

FEASIBILITY ANALYSIS

TECHNICAL EVALUATION

- Will product quality be improved or maintained ?
- Are the new equipment, materials, or procedures compatible with production operating procedures, work flow, and production rates ?
- How long will production be stopped during system installation ?
- Will additional labor be needed ?
- Will workers need special expertise to run equipment ?
- Is their enough utility capacity to run the equipment ? Or, must it be installed at increased capital cost ?
- Is space available ?
- Will the vendor provide acceptable service ?
- Is the system safe for workers ?
- Will the system create other environmental problems ?

FEASIBILITY ANALYSIS

ECONOMIC EVALUATION

- Use the framework of Total Cost Assessment to account for:
  - Direct costs
  - Indirect costs
  - Liability costs
  - Less tangible benefits

FEASIBILITY ANALYSIS

DIRECT COSTS

- Capital expenditures
  - Buildings
  - Equipment and installation
  - Utility connections
  - Project engineering
- Operation and maintenance
- Expenses
  - Raw materials
  - Labor
  - Waste disposal
  - Water and energy
  - Value of recovered material

INDIRECT COSTS

- Administrative Costs
- Regulatory Compliance Costs
  - Permitting
  - Recordkeeping and reporting
  - Monitoring
  - Manifesting
- Insurance
- Worker's compensation
- On-site waste management
- On-site pollution control equipment operation

FEASIBILITY ANALYSIS

LIABILITY COSTS

- Penalties
- Fines
- Personal injury
- Property damage
- Environmental cleanup costs

FEASIBILITY ANALYSIS

LESS TANGIBLE BENEFITS

- Increased sales due to:
  - Improved product quality
  - Enhanced company image
  - Consumer trust in environmentally sound products
- Improved supplier/customer relations
- Reduced health maintenance
- Increased productivity due to improved employee relations
- Improved relations with regulators

CHAPTER 4
FINANCIAL CONSIDERATIONS[1]

4.1 INTRODUCTION

As companies incorporate pollution prevention approaches in their strategic planning, capital investment priorities, and process design decisions, it is vital that they understand both the quantitative and qualitative dimensions of assessing pollution prevention projects. These projects tend to reduce or eliminate costs that may not be captured in cursory financial analyses due to the way the costs are categorized and allocated by conventional management accounting systems. Additionally, pollution prevention projects often have impacts on a broad range of issues, such as market share and public impact, that are difficult to quantify but that can be of strategic importance. Identifying and analyzing all costs and less tangible items is an important step in an evaluation of the potential benefits of a pollution prevention project.

The process for assessing pollution prevention projects, particularly the financial analysis component, fits with the framework of the standard capital budgeting model. However, the process described here, referred to as ***capital budgeting for pollution prevention projects*** expands on and broadens the way capital budgeting is often practiced.[2] The approach described here attempts to address this tendency of financial analyses to omit environmentally-related costs, which typically are lumped into overhead accounts, allocated to products, or overlooked in the cost identification process. This chapter also focuses relatively greater attention on the more qualitative impacts of projects. While this is not the only way to evaluate a project, it does provide an accurate method for ensuring that important benefits and potential impacts are included in the analysis.

Section 4.2 provides an overview of capital budgeting and the key concepts and factors used to perform a financial analysis of a pollution prevention project. Section 4.3 describes how to establish a cost baseline, a necessary first step in any evaluation of pollution prevention projects. Section 4.4 presents a process for evaluating projects against the baseline. Section

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1 This chapter is derived from the United States Environmental Protection Agency document "A Primer for Financial Analysis of Pollution Prevention Projects".

2 The standard capital budgeting model in theory incorporates all changes in operating and administrative costs; anecdotal evidence, however, suggests that in practice many "indirect costs" are excluded.

4.5 introduces the various intangible qualitative costs to be considered in conjunction with a financial analysis to determine the real impact of a proposed project.

4.2 KEY CONCEPTS IN CAPITAL BUDGETING

Pollution prevention can take many forms -- from simple "housekeeping" improvements, which cost little to carry out, to the installation of expensive capital equipment. Although many pollution prevention projects, such as material substitution or process redesign, do not require large outlays for the purchase of equipment, they may require significant engineering expense, create incremental costs or savings, or may require extensive qualitative assessment related to such issues as product quality or employee health and safety. The analytical tools described in this section are applicable to the assessment of most pollution prevention initiatives that fit under the umbrella of the capital budgeting process.

Pollution prevention projects are a recent addition to the list of typical capital budgeting projects and generally include:

- New manufacturing equipment;
- Replacement equipment; and
- Plant expansion and construction.

Capital budgeting is a process of evaluating capital investment options based on a company's needs and analyzing the impact of an investment on a company's cash flow over time. Pollution prevention and other capital projects are justified by showing how the project will increase revenue and how the added revenue will not only recover costs, but substantially increase the company's earnings as well. Financial tools demonstrate the importance of the pollution prevention investment on a life cycle or total cost basis; in terms of revenues, expenses, and profits. Key concepts and factors used in capital budgeting are described below:

Life cycle costing: Also referred to as Total Cost Accounting, this method analyzes the costs and benefits associated with a piece of equipment or a procedure over the entire time the equipment or procedure is to be used. The concept was first applied to the purchase of weapons systems for the U.S. military. Experience showed initial purchase price was a poor indicator of the total cost; costs such as those associated with maintainability, reliability, disposal/salvage value, and training/education needed to be considered in the financial decision making process. Similarly, in justifying pollution prevention, all benefits and costs must be spelled out in the most concrete terms possible over the life of each option.

Present worth: The importance of present worth, or present value, lies in the fact that time is money. The preference between a dollar now or a dollar a year from now is driven by the fact that the dollar in-hand can earn interest. Mathematically, this relationship is as follows:

$$PresentValue = \frac{Future\ Value}{(1 + interest)^{Number\ of\ years}} \qquad P = \frac{F}{(1+r)^n}$$

where P is the present worth or present value, F is the future value, r is the interest or discount rate, and n is number of periods. In the above example $1 in one year at 5% interest compounded annually would have a computed present value of:

$$P = \frac{\$1.00}{(1+.05)^1} = \$.95$$

Because money can "work," at 5% interest, there is no difference between $.95 now and $1.00 in one year because they both have the same value at the present time. Similarly, if the $1 was to be received in 3 years, the present value would be:

$$P = \frac{\$1.00}{(1+.05)^2} = \$.86$$

In considering either multiple payments or case into and out of a firm, the present values are additive. For example, at 5% interest, the present value of receiving both $1 in one year and $1 in 3 years would be $.95 + $.86 = $1.81. Similarly, if one was to receive $1 in one year, and pay $1 in 3 years, the present value would be $.95 - $.86 = $.09. As a result, present worth calculations allow both costs and benefits which are expended or earned in the future to be expressed as a single lump sum at their current or present value.

Comparative factors for financial analysis: The more common methods for comparing investment options all utilize the present value equation presented earlier. Generally, one of the following four factors is used:

- ***Payback period:*** This factor measures how long it takes to return the initial investment capital. Conceptually, the project with the quickest return is the best investment.

- ***Internal rate of return:*** This factor is also called "return on investment" or ROI. It is the interest rate that would produce a return on the invested capital

equivalent to the project's return. For example, a pollution prevention project with an internal rate of return of 23% would indicate that pursuing the project would be equivalent to investing the money in a bank and receiving 23% interest.

- ***Benefits cost ratio:*** This factor is a ratio determined by taking the total present value of all financial benefits of a pollution prevention project and dividing by the total present value of all costs of the project. If the ratio is greater than 1.0, the benefits outweigh the costs and the project is economically worthwhile to undertake.

- ***Present value of net benefits***: This factor shows the worth of a pollution prevention project as a present value sum. It is determined by calculating the present values of all benefits, doing the same for all costs and subtracting the two totals. The new result would be an amount of money that would represent the tangible value of undertaking the project.

While firms can use any of these factors, the importance of life cycle costing or total cost analysis makes the present value of net benefits the preferred method.

4.3 ESTABLISHING A BASELINE

The first step in determining the cost of a project is to establish a baseline for the analysis. The "do-nothing" or "status quo" alternative is generally used as a baseline. Then any changes in material use, utility expense, etc., for other options being considered are measured as either more or less expensive than the baseline.

McHugh[3] outlines four tiers of potential costs that should be examined relative to pollution prevention projects:

- Tier 0: Usual costs such as direct labor (wages and benefits, including vacation, holidays, etc.), raw materials used in the production process, and equipment used for production;

- Tier 1: Hidden costs such as monitoring expenses, reporting and record keeping, and permit requirements.

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[3] McHugh, R.T., "The Economics of Waste Minimization," Hazardous Waste Minimization, McGraw-Hill, 1990.

- Tier 2: Future liability costs such as costs to respond to or clean up accidental releases of contaminants or other incidents, personal injury, property damage, etc.

- Tier 3: Less tangible costs such as consumer response, employee relations, and corporate image.

McHugh's Tier 0 and Tier 1 costs cover typical direct and indirect costs such as engineering, materials, labor, construction, utilities, depreciation, recordkeeping, etc., as well as waste collection and transportation services, raw material consumption (increase or decrease) and production costs. Conventional cost accounting schemes tend to spread Tier 2 costs indiscriminately over all activities, regardless of actual use. Full cost accounting seeks to uncover these costs and properly assign them to specific activities. Often such determinations require an estimate of the amount of a resource that is consumed in the production process (e.g., the amount of electricity used by a piece of equipment).

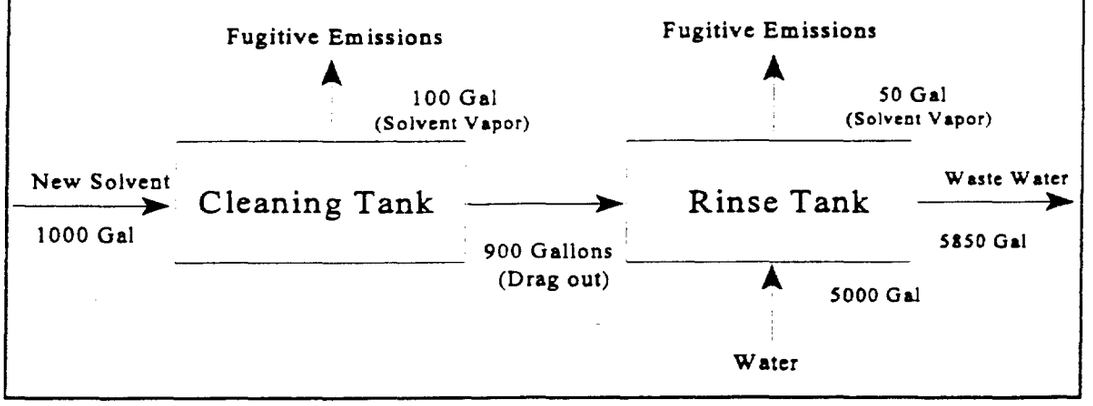
Tier 2 and Tier 3 represent intangible costs, which are more difficult to define and include liabilities that could arise from third party lawsuits for personal or property damages, and benefits of improved safety and work environments. Although it is difficult to accurately account for these intangible costs, they can be most important. Section 4.5 provides additional information on these costs and their role in any analysis of potential pollution prevention projects.

4.3.1 Measuring Baseline Costs

The simplest way to establish a baseline cost is to add up the relevant input and output materials for the process and then compute their appropriate dollar value. This is done by first completing a material balance for the process (see chapter 4 for a discussion on preparing a material balance). **Exhibit 4-1** shows an example material balance.

Once the material balance is completed, determining the baseline cost becomes a simple matter of pricing each input and output and multiplying their volumes by the appropriate unit.

Exhibit 4-1: Annual Material Balance for the Hazardous Solvent



An example using a small electronics firm illustrates how to compute baseline costs. The firm cleans metal parts with a chlorinated solvent that is hazardous to workers. In addition,the wastewater that results from rinsing the parts must be treated before it can be discharged to the environment. For these reasons, the company is considering ways to reduce the volume of wastewater generated. The firm's current costs for parts cleaning are provided in **Exhibit 4-2**.

Exhibit 4-2
Current Costs for Parts Cleaning

Item	*Cost/Unit*	*# Units*	*Cost/Year*
Solvent	$3.25/gal	1,000 gal	$ 3,250.00
Water	$2.10/1,000 gal	5,000 gal	$10.50
Waste Treatment	$2.50/gal	5,850	$14,625.00
		Total Annual Cost	**$17,885.50**

Although the next step would be to examine expected business changes such as business expansions, new accounts, rising prices, etc., for simplicity, the **Exhibit 4-2** costs and volumes are assumed to be constant. This means that the current annual costs will be same in the out-years except for one very important aspect, the time value of money.

Due to the assumptions made regarding constant cost, the $17,885 annual cost shown in **Exhibit 4-2** can be assumed to repeat each year. The present value calculations shown earlier in the chapter enable this annual expenditure to be expressed as a single sum which includes the effects of interest. The first year's cost, assuming the bills are paid at the end of the year, would be the amount of money that would have to be banked starting today, to pay a $17,885 bill in one year. Using a 10% interest rate, the calculation is as follows:

$$P = \frac{\$17,885}{(1+10)^1} = \$16,260$$

This means that if $16,260 is banked at 10% interest, it would provide enough money to pay the $17,885 bill at the end of the year. Similarly, the second, third, fourth, etc., years expenditures can also be expressed in present value. This is done in Exhibit 4.3.

Exhibit 4-3
Present Value Calculations For The Electronics Firm

Year	*Expenditure*	*Present Value*
1	$17,885	$16,260
2	$17,885	$14,781
3	$17,885	$13,437
4	$17,885	$12,216
5	$17,885	$11,105
6	$17,885	$10,096
7	$17,885	$9,178
8	$17,885	$8,343
9	$17,885	$7,585
10	$17,885	$6,895
Total		$109,896

The bottom line to the analysis is that the total cost of the current cleaning system over the next 10 years, given a 10% interest rate, is $109,896 in present value terms. In other words,

$110,000[4] invested today at 10% interest would be sufficient to pay the entire material and disposal costs for the parts cleaning operation for the next 10 years. Hence, any changes to the operation of the firm can now be compared to this $110,000 baseline. Any change which would result in a lower 10 year cost would be a benefit because it would save money; any option with a higher cost would be more expensive and should not be adopted from a financial or economic standpoint.

Simple pollution prevention projects often require little more financial justification than the savings related to Tier 0 or possible Tier 1 costs. However, as a firm gets more sophisticated, the less tangible Tier 2 and 3 costs are likely to become more important. Even if these costs cannot be accurately predicted, in cases where two investment options appear to be financially equivalent, if one is a pollution prevention project, the Tier 2 and 3 consideration can favor that option.

4.3.2 The Effect of Pollution Prevention Projects on Revenues and Expenses

With few exceptions, the goal of most business endeavors is to make a profit. As a result, the costs and benefits cash flows for each option can be related to the basic profit equation:

Revenues - Expenses = Profit

The most important aspect is that profits can be increased by either an increase in revenues or a decrease in expenses. A benefit of pollution prevention is often lowered expenditures and increase profit. The remainder of this section examines the different categories of pollution prevention revenues and expenses.

Revenues: In its simples definition, revenue is money coming into the firm; from sales of goods or services, rental fees, interest income, etc. From the profit equation, it can be seen that a revenue increase leads to a direct increase in profit and vice versa if all other revenues and expenses are held constant.[5]

Because a pollution prevention project can either increase or decrease production rates, it is important to examine the project's effects on revenues. For example, often firms can cut wastewater treatment costs if water use (and in turn the resulting wastewater flows) is

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4 Given the number of assumptions regarding costs, growth, etc., that must be made in these calculations, rounding the calculated values to 2 significant figures is generally wise.

5 The condition of other expenses/revenue being held constant is assumed throughout this chapter.

regulated to non-peak times at the wastewater treatment plant. However this limitation on water use could hamper production.

Consequently, even though the firm's actions to regulate water use could reduce wastewater charges, unless alternative methods are found to maintain total production, revenue could also be decreased.

Conversely, a change in production procedure as a result of a pollution prevention project could increase revenue. For example, a process change such as moving from liquid to dry paint stripping can not only reduce water consumption, but also affect production output. Since cleanup time from dry paint stripping operations (such as bead blasting) is generally much shorter than from using a hazardous, liquid based stripper, it could mean not only the elimination of the liquid waste stream (the direct objectives of the pollution prevention project), but less employee time spent in the cleanup operation. Hence, production, and in turn revenues, could be enhanced through pollution prevention.

Although less common, one more potential revenue effect is the generation of marketable byproducts as a result of pollution prevention efforts. Hence, pollution prevention has the potential to either increase or decrease revenue and profits.

Expenses: Expenses are moneys leaving the firm to cover the costs of operations, maintenance, insurance, etc. The major cost categories for pollution prevention investment consideration and their effects on total expenses are outlined below.

- ***Depreciation expense:*** If the pollution prevention project involves the purchase of capital equipment with a limited life (such as storage tanks, recycle or recovery equipment, new solvent bath systems, etc.), the entire cost is not charged against the current year. Instead a system of depreciation spreads that expense over time. Depreciation expense calculations allocate the equipment's procurement costs (including delivery charges, installation, start up expenses, etc.) by taking a percentage of the cost each year over the life of the equipment.

  For example, if a piece of equipment was to last 10 years, an accounting expense of 10% of the procurement cost for the equipment would be charged each year.[6]

[6] This method is called straight-line depreciation. Although there are other methods available since straight-line depreciation is easy to compute, it is the method of choice in the chapter. Investment projects under consideration at any given time should use the same depreciation method to allow for accurate comparisons of expense and revenue impacts between the alternatives.

- ***Interest expense:*** Pollution prevention investment implies that one of two things must occur; either a firm must pay for the project out of its own cash, or it must finance the cost by borrowing money from a bank, seeking funds from private sources, etc. In the case where a firm pays for a pollution prevention project out of its own cash reserves, the action is sometimes called an opportunity cost, which is discussed later. If cash for the project must be borrowed, there is an interest charge connected with using someone else's money.

- ***Labor expense:*** In most cases, the firm's labor requirements will change due to the pollution prevention project. As pointed out in the dry paint stripping example, this could be a positive effect that increases available productive time, or, if extra man hours are required to run new equipment, perform preventive maintenance, etc., there could be a decrease in employees' productive time.

  When computing labor expenses, the Tier 1 costs could be significant. For example, if a material substitution project eliminated a hazardous input material which eliminated a hazardous waste, there could be a significant decrease in labor required to handle and store the waste in a safe manner. Hence, both direct, Tier 0, expenses and secondary, Tier 1, expenses (e.g., hours per week for preventive maintenance on equipment) can have an effect on manpower costs.

- ***Training expense:*** Pollution prevention may also involve the purchase of equipment or new, non-hazardous input materials which require additional operator training. In computing the total training costs, both the direct costs and the man hours spent in training must be considered as an expense. In addition, any other costs for refresher training or training for new employees, which is above the level currently needed, must be included in the analysis.

- ***Floor space expense:*** As with any opportunity costs, the floor space cost must be based on the value of alternative uses. For example, multiple rinse tanks have long been used to reduce water use in electroplating. If a single dip rinse tank of 50 square feet is replaced with a cascade rinse system of 65 square feet, then the floor space expense would be the financial worth of the extra 15 square feet and must be included as an expense in the financial analysis for the pollution prevention project. Unfortunately, computing this floor space opportunity cost is not always as straightforward as it is with the case of training costs. In instances where little square footage is required, there may be no other use for the floor space which implies a zero cost. In other cases, if the area is currently only being used for storage of extra parts, bench stock,

feed materials, etc., the costs may involve determining the worth of having a drum of chemical or an extra part closer to the operator.

- ***Insurance expense:*** Depending on the pollution prevention project, insurance expense could either increase or decrease. For example, if a heat recovery still was added to a process operation, fire insurance premiums could increase. Or if the use of a hazardous material is eliminated, health insurance costs for employees could go down. Depending upon the premium change (if any), expenses, and in turn, profits could increase or decrease as a result of the pollution prevention project.

Other factors that could affect the decision whether to implement a pollution prevention project include cash flow and opportunity cost. Although cash flow does not have a direct effect on the firm's revenues or expenses, the concept must be considered before undertaking any pollution prevention project. If the project involves procurement costs, they often must be paid upon delivery of the equipment. Conversely, cash recovery could take years. Hence, three things can affect a firm's available cash. First, cash is used at the time of purchase. Second, it takes time to realize financial returns from the project through enhanced revenues or decreased expenses. Finally, depreciation expense is calculated at a much slower rate than the initial cash is spent. As a result of the investment, a firm could find itself cash poor.

Opportunity cost is also important because to the extent a firm uses its cash to purchase equipment for a project, it forgoes the opportunity to use that cash for other investments. As a result, revenues that could have been generated by the cash (e.g., interest resulting from saving the money) should be treated as an expense and reduce the value of the pollution prevention project.

Although it is true that the cash will not be available for other investments, opportunity cost should not be considered as an expense. The opportunity lost by using the cash is considered when the pollution prevention project competes for the firm's funds and is expressed by one of the financial analysis factors discussed earlier (e.g., net value of present worth, pay back period, etc.). It is this competition for a firm's limited funds that encompasses opportunity cost, and opportunity cost should not be accounted directly against the project's benefits.

A minimum rate of return or hurdle rate is often used to express this opportunity cost competition between investments. For example, if a firm can draw 10% interest on cash in the bank, then 10% would be a valid choice for the hurdle rate as it represents the firm's cash opportunity cost. Then in analyzing investment options under a return on investment criteria, not only would the highest returns be selected, but any project which pays the firm a return less than the 10% hurdle rate would not be considered.

Pollution prevention has good investment potential. In reducing or eliminating waste generation and the related disposal/treatment expenses, pollution prevention can have a significant impact on the firm's bottom line. Even in cases where revenues are not generated, reducing the expenses and liabilities associated with managing wastes represents a substantial reduction in overall expenses and an increase in profit.

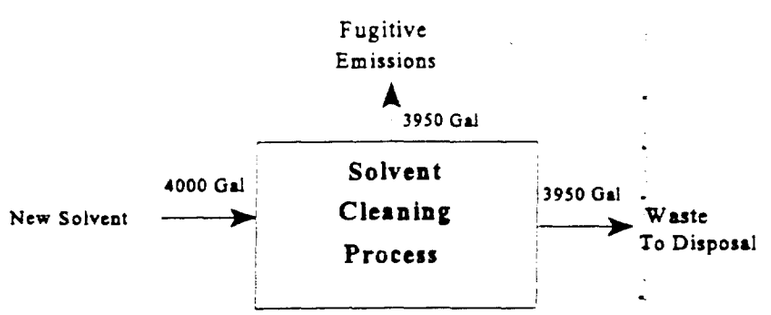
4.4 EVALUATING POLLUTION PREVENTION OPPORTUNITIES

This section describes how to analyze a pollution prevention project. The hypothetical firm introduced in the previous section takes in used parts, cleans them in a dip tank using a hazardous solvent, and applies a new finish. The financial analysis will compare the current solvent cleaning operation with two pollution prevention alternatives: a solvent recycle system and non-hazardous material substitution.

4.4.1 Establishing the Baseline

As indicated in Section 4.3, the first step is to define the baseline cost. Once this is done, it is possible to evaluate the financial effects of any change to business as usual. **Exhibit 4-4** shows the material balance for the current system.

Exhibit 4-4: Baseline Material Balance



Based on the material balance, annual costs can be assigned for the process. The resulting cash flow is shown in **Exhibit 4-5**.

Exhibit 4-5
Baseline Costs

Element	*Rate*	*Annualized Costs*
Procurement Expenses		None
Operations Expenses		
-- Utilities		N/A[7]
-- Operating Expense		N/A
-- Maintenance/Spare Parts		N/A
-- Input Solvent	$3.50/gal	$14,000
-- Waste Disposal	**$2.50/gal**	$9,875

To express these annual costs in present value terms, a time reference must be selected so that each option can be considered over the same length of time. Since the recycle equipment has an expected life of 10 years, the baseline and both options will be examined over this time period.

For the purpose of illustration, the firm's discount rate (the firm's internal interest or "hurdle" rate) is assumed to be 15%, and the inflation rate is assumed constant at 5% per year. Since the discount rate and inflation rate work against each other (i.e., interest makes your money more valuable over time and inflation makes it less valuable over time), they can be combined. However, for simplicity, they are treated separately in this analysis. All present value computations are made using 15% interest and all expenses are increased at an inflationary rate of 5% per year.

To account for prices that rise faster than inflation, annual real price increases (in excess of inflation) of 1% of the cost of solvent and 4% of the cost of disposal are assumed. In these cases, the cost of solvent increases 6% per year (5% inflation + 1% real price increase) and waste disposal increases 9% per year. Given these assumptions, the baseline expenses for the next 10 years are shown in **Exhibit 4-6**.

[7] These expenses are not applicable for the baseline because it is only necessary to consider increases/decreases when analyzing the options.

Exhibit 4-6			
Ten Year Baseline Costs			
	Annual Cost		
Year	Item	w/o Recycle	Annual Total
1	New Solvent	$14,000	
	Waste Disposal	$9,875	
			$23,875
2	New Solvent	$14,840	
	Waste Disposal	$10,764	
			$25,604
3	New Solvent	$15,730	
	Waste Disposal	$11,732	
			$27,462
4	New Solvent	$16,674	
	Waste Disposal	$12,788	
			$29,462
5	New Solvent	$17,674	
	Waste Disposal	$13,939	
			$31,613
6	New Solvent	$18,734	
	Waste Disposal	$15,194	
			$33,928
7	New Solvent	$19,859	
	Waste Disposal	$16,561	
			$36,420

Ten Year Baseline Costs			
8	New Solvent	$21,050	
	Waste Disposal	$18,051	
			$39,101
9	New Solvent	$22,313	
	Waste Disposal	$19,676	
			$41,989
10	New Solvent	$23,652	
	Waste Disposal	$21,477	
			$45,099

In many cases, firms simplify these calculations by assuming costs will be constant over the life of the project. If this is the case, then all outyear costs would be same as was done with the **Exhibit 4-5** example.

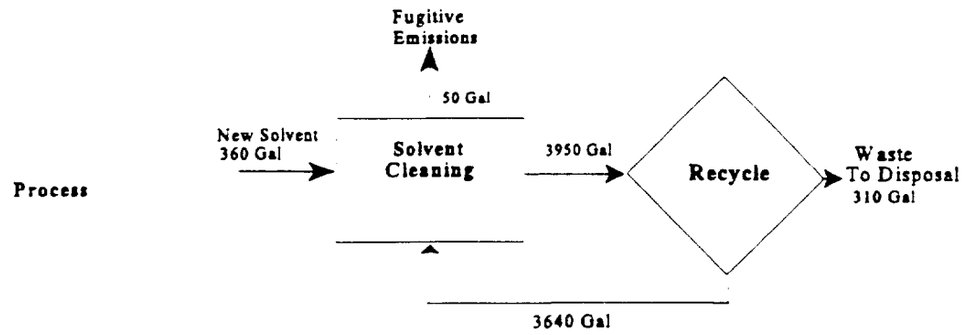
The intermediate step in the financial analysis will be to compare the annual costs of the two pollution prevention options with the annual costs of the baseline process. Then the present value of the annual cost savings (or cost increase) of the options can be calculated. This will be done for the base line and both options simultaneously at the end of the analysis.

The final step will be to sum the present values from each year to obtain the net present value. The net present value represents the quantifiable worth of the project.

4.4.2 Examining The Recycle Option

As before, the first step will be establish the mass balance, as shown in **Exhibit 4-7**.
As is the case with many recycle options, a salable by-product is generated (the recycled solvent), but instead of offering the solvent for sale, the firm is using it as an input to offset the cost of new solvent so there is no revenue impact. Further, since the actual cleaning operation has not changed, there should be no change in production rate as result of this option. As a result, there are no revenue impacts to consider.

Exhibit 4-7: Mass Balance



This material balance is converted to a cash flow in **Exhibit 4-8**. As mentioned earlier, the recovery equipment has a life of 10 years. Further, there is no salvage value; the solvent must be chemically treated at the end of year 5 to retain its effectiveness at a cost of $1000; and no additional permits are required to operate or install the equipment.

Exhibit 4-8
Costs for Solvent Recycling

Element	*Rate*	*Base Year Costs*
Procurement Expenses		
Recycle Equipment:		
Tanks, Pumps, Mixers, etc.		$40,500
Installation: Design, Piping, Labor, etc.		$20,000
Contingency (@10%)		$6,000
	Total:	$66,500
Operations Expenses		
Recovery System		
Utilities		$240

Element	*Rate*	*Base Year Costs*
Operating Expense	1hr/day@$20/hr	$5,000
Maintenance/Spare Parts	5% of Capital Cost	$3,325
Input Solvent	$3.50/gal	$1,260
Waste Disposal	$2.50/gal	$775

Other expenses to consider include:

- Depreciation. It is assumed to be straight line, with the procurement costs expense at 10% each year for 10 years.

- Interest. The firm borrowed the capital costs, will make annual payments for 3 years, and must pay 12% interest annually. Note: the principle ($66,500) will be repaid in three equal installments. The interest expense is calculated for each year based upon the current balance. (The actual monies borrowed, or repaid, are neither revenues nor expenses and do not appear in the financial analysis).

- Labor. The equipment requires 1 hour of maintenance per day. This expense ($20/hour) is included in the operations expenses listed above. For simplicity, the wage rate is assumed constant except for cost of living increases due to inflation.

- Training. Training was supplied by the recycle equipment supplier with training on site so there are no direct costs. Three operators must spend 2 hours each learning the operations. Their wage costs are also taken as $20/hour.

- Floor Space. The equipment is relatively compact, will be installed integral to the process, and carries a zero floor space expense.

As done with the baseline, annual costs for the recycling option must also be spread over time as they will actually occur. **Exhibit 4-9** shows the costs, by year, for the 10 year life of the recycle equipment.

Exhibit 4-9
Ten Year Costs for Recycle Option

Year	*Item*	*w/Recycle*	*Total*
1	Interest Expense ($66,500 x 12%)	$7,980	
	Depreciation Expense	$6,600	
	Initial Training	$ 120	
	Operating Expenses		
	(Labor, Utilities, Maintenance)	$8,565	
	New Solvent	$1,260	
	Waste Disposal	$ 775	
			$25,300
2	Interest Expense ($44,333 x 12%)	$5,320	
	Depreciation Expense	$6,600	
	Operating Expenses (5%/yr. increase)	$8,993	
	New Solvent (6%/yr. increase) (360 gal.)	$1,336	
	Waste Disposal (9%/yr. increase)	$845	
			$23,094
3	Interest Expense ($22,166 x 12%)	$2,660	
	Depreciation Expense	$6,600	
	Operating Expenses	$9,442	
	New Solvent	$1,416	
	Waste Disposal	$921	
			$21,039
4	Depreciation Expense	$6,600	
	Operation Expenses	$9,915	
	New Solvent	$1,501	
	Waste Disposal	1,004	
			$19,020
5	Depreciation Expense	$6,600	
	Operating Expenses	$11,410[9]	
	New Solvent	$1,591	
	Waste Disposal	$1,094	

Year	*Item*	*w/Recycle*	*Total*
			$20,695
6	Depreciation Expense	$6,600	
	Operating Expenses	$10,931	
	New Solvent	$1,686	
	Waste Disposal	$1,192	
			$20,409
7	Depreciation Expense	$6,600	
	Operating Expenses	$11,477	
	New Solvent	$1,787	
	Waste Disposal	$1,300	
			$21,164
8	Depreciation Expense	$6,600	
	Operating Expenses	$12,051	
	New Solvent	$1,895	
	Waste Disposal	$1,417	
			$21,963
9	Depreciation Expense	$6,600	
	Operating Expenses	$12,654	
	New Solvent	$2,008	
	Waste Disposal	$1,544	
			$23,806
10	Depreciation Expense	$6,600	
	Operating Expenses	$13,287	
	New Solvent	$2,129	
	Waste Disposal	$1,683	
			$23,699

Again, these annual costs will be compared to the baseline after all cash flows for the options have been computed.

4.4.3 Evaluating Material Substitution

This option consists of replacing the hazardous solvent used for cleaning in the baseline case with a non-hazardous cleaner which is used in the same manner. The firm has been fortunate to find a cleaning solution which is sewerable and does not require disposal as a hazardous waste. The cost of sewering the 3,950 gallons is assumed to be negligible.

In pollution prevention projects that involve substituting a non-hazardous material for a hazardous material, part of the analysis must consider how well the new product or process works in relation to the current practice. In this example, it is assumed no operational changes are required so production levels can be maintained. However, the cost of the new cleaner is nearly 25 percent higher: $4.60/gal. The first-year costs for implementing this option are shown in **Exhibit 4-10**.

Exhibit 4-10
First Year Costs for the Material Substitution Alternative

Element	*Rate*	*Annualized Costs*
Procurement Expenses		None
Operations Expenses:		
Operating Expense		N/A
Maintenance/Spare Parts		N/A
Input Solvent	$4.60/gal	$18,400
Waste Disposal		$ 00
Training		$120

Other expenses to consider include:

- Depreciation. Since there is no capital expenditure, there is no equipment to depreciate.
- Interest. The company has the cash to absorb the additional cleaner cost without borrowing any additional capital. Hence, there is no interest expense.
- Labor. There is no additional equipment maintenance requirement and the wage rate is again constant except for cost of living increases due to inflation.

- Training. As before, it is assumed that the vendor provides the training and 3 operators spend 2 hours learning how to handle, test, and maintain the new cleaner. Their wage rate is taken as $20/hour (from the previous example).

- Floor space considerations. The current solvent storage capacity for the firm is adequate for the new material.

With the same assumptions regarding cost increases, the annual costs for switching to the non-hazardous cleaner, over the ten year period, are shown in **Exhibit 4-11**.

Exhibit 4-11
Ten Year Material Substitution Costs (5%/Yr. Increases)

Year	*Item*	*Annual Cost*
1	New Cleaner	$18,520
2	New Cleaner	$19,320
3	New Cleaner	$20,286
4	New Cleaner	$21,300
5	New Cleaner	$22,365
6	New Cleaner	$23,484
7	New Cleaner	$24,658
8	New Cleaner	$25,891
9	New Cleaner	$27,185
10	New Cleaner	$28,544

4.4.4 Making the Financial Comparison

With all the annual costs computed, the final comparisons can be made. **Exhibit 4-12** shows the annual baseline costs (from **Exhibit 4-6**) in the first column; columns 2 and 3 show the annual costs for recycle (from **Exhibit 4-9**) and the increase or decrease from the baseline; and finally, columns 4 and 5 show the annual costs for material substitution (from **Exhibit 4-11**) and their associated change from the baseline.

Exhibit 4-12
Annual Cost Comparison

Year	*Baseline*	*Recycle*	*Savings*	*Material Substitution*	*Savings*
1	23,875	25,300	(1,425)	18,520	5,355
2	25,604	23,094	2,510	19,320	6,284
3	27,462	21,039	6,423	20,286	7,176
4	29,462	19,020	10,442	21,300	8,162
5	31,613	20,695	10,916	22,365	9,248
6	33,928	20,409	13,519	23,484	10,444
7	36,420	21,164	15,256	24,658	11,762
8	39,101	21,963	17,138	25,891	13,210
9	41,989	23,806	18,183	27,185	14,804
10	45,099	23,699	21,400	28,544	16,555

If an option's annual costs are less than the baseline, the difference is considered a benefit. Conversely, if the option's annual costs are higher than the baseline (indicated by parenthesis), the difference is considered a cost. So that the two options can be compared, the final steps are to bring each option's costs and benefits back to present value, compute the net difference, and make the financial decision. These calculations are shown in **Exhibit 4-13**. The present value calculation uses the formula from page __ with the interest rate set at 15%. (Recall that 15% was set as the example firm's "hurdle" rate or acceptable internal interest rate).

$$P = \frac{F}{(1+r)^n}$$

Exhibit 4-13
Present Values of the Costs and Benefits

	Recycle Option		*Material Substitution*	
Year	*Difference*	*Present Value*	*Difference*	*Present Value*
1	(1,425)	(1,239)	5,355	4,657
2	2,510	1,898	6,284	4,752
3	6,423	4,223	7,176	4,718
4	10,442	5,970	8,162	4,666
5	10,916	5,427	9,248	4,598
6	13,519	5,844	10,444	4,515
7	15,256	5,735	11,762	4,422
8	17,138	5,602	13,210	4,318
9	18,183	5,169	14,804	4,208
10	21,400	5,290	16,555	4,092
NET PRESENT VALUE		$43,919		$44,946

4.4.5 Making the Final Decision

In this example, both options display a positive effect on profitability. The two proposals each generate a new benefit compared to the baseline. Likewise, the proposals also meet the firm's internal hurdle rate (15%), because their present values are positive when calculated using a 15% discount rate.

The final task is to select between the two options. In that they have the same present worth of new benefits, they are equivalent under the financial criteria. However, as previously discussed, when projects appear financially equivalent, consideration of other tier costs can swing favor toward a particular option. The above analysis considered only Tier 0 and Tier 1 costs. Eliminating the use of hazardous solvent limits the potential intangible Tier 2 and 3 costs for cleanup, lawsuits, etc. Given these considerations, and the fact that material substitution is higher on the pollution prevention hierarchy, the material substitution option is clearly the most beneficial option.

4.5 THE IMPORTANCE OF CONSIDERING INTANGIBLE COSTS

As stated earlier, Tiers 2 and 3 include less tangible considerations such as effects on product quality, productivity, public image, market share, stakeholder relations employee health and safety, and financial liability which, while very important, are more difficult to account for. This section provides some guidance on addressing these factors and highlights their significance. Some of these issues, such as public impact, tend to be straightforward. The impact of a pollution prevention project is presumed to be positive, and the question is "to what extent and how quickly". Other issues, such as product quality, arise as (possibly) unintended consequences of the effort to reduce waste. In these cases, pollution prevention changes may have either a positive or negative impact. After determining the nature of the impact, it is important to consider ways to restructure the project to minimize unwanted consequences.

Product Quality. Customers are increasingly demanding environmentally-friendly products yet are rarely willing to surrender price or quality to achieve their demands. A pollution prevention project that is detrimental to product quality (e.g., through inferior material substitution or process changes that fail to meet design specifications) will rapidly translate into lost sales or into increased costs of rework and downtime. Alternatively, a pollution prevention initiative may improve quality and/or enable a product to be marketed as "green," a benefit that may engender greater market acceptance and boost sales. Concerns about impacts on quality need to be addressed up-front by:

- Conducting sufficient engineering review and testing before specifying equipment or changing a product or process;
- Securing guarantees from the vendor;
- Planning for incremental ramp-up of production using the new process or new material; and/or
- Securing customer feedback to determine what impact changes may have on consumer acceptance.

A project proposal should include a section on product quality that outlines possible concerns and describes in detail the measures that have been taken to anticipate, address, and resolve these concerns. Almost nothing can kill a project faster than the fear that it may harm product quality, and the justification package must allay those fears as much as possible.

Impact on productivity/capacity: Process changes resulting from implementing a pollution prevention project could potentially increase or decrease the productivity and/or effective

capacity of a plant. For example, an aqueous degreaser may reduce solvent use but may require a longer cycle time to remove contaminants effectively, thereby increasing throughput time and lowering productivity. On the other hand, installing new equipment to add a parallel process line might both reduce solvent use required for product changeovers and increase productive capacity. As with determining effects on product quality, engineering review of new process specifications is crucial to assess a project's effect on production. Thorough review should enable the impact on productivity/capacity to be estimated with sufficient accuracy to permit its inclusion in the financial analysis. If this is not possible, the potential impacts should be explored and described qualitatively, perhaps using sensitivity analysis to quantify their effect.

Public image. Having an "environmentally-correct" image continues to become more important. Many companies now tout their "green" credentials. For example, Sun Oil Company recently launched a major ad campaign to publicize its signing of the CERES (formerly Valdez) principles, the first Fortune 500 company to do so. While a good public image is important for its own intangible reasons, its value is increasing as the link between a company's public image and market acceptance of its products becomes stronger. Image can be especially important to a company that has suffered a poor environmental reputation. For example, Polaroid, which had received a lot of negative publicity for its toxic discharges, now promotes its pro-active strategies of pollution prevention and recycling. The company has received widespread recognition for many of its innovative environmental programs.

Although almost any pollution prevention project can bolster the environmental record of a business, one that directly addresses publicly-recognized problems can be especially valuable. If a proposed pollution prevention project eliminates a source of bad publicity, such as the discharge of effluent that discolors a waterway, the public relations benefits of the project should be strongly emphasized in the justification package.

Market share (i.e., consumer acceptance). Numerous surveys have documented the trend of green consumerism, and companies have responded by emphasizing environmental attributes in new product development. The growing inclination of consumers to buy "green" refers to purchases of products or services that are environmentally-benign or that are offered by companies with good environmental records. A pollution prevention project that "creates" a green process or product may have a significant impact on sales, depending upon customer demand. A project justification proposal could promote the value of this factor by including survey data related to the particular industry or product type. Additionally the report could show how a specific product or company, in a similar situation or industry, either gained market share after emphasizing its green qualities or lost market share due to a poor environmental record. To further demonstrate the significance of this issue, developing computer-generated scenarios based on experiences of similar companies could be valuable in demonstrating how even small impacts on market share can generate large returns on the bottom line.

Stakeholder relations. The term "stakeholders" can broadly include almost any person, group or organization with which a business has contact: employees, stockholders, lending institutions, customers, suppliers, surrounding communities, and others. Though small, privately-held firms may not be as susceptible to shareholder pressure as large corporations, they may be equally or more sensitive to the interests of such other stakeholders as the surrounding community and employees. For businesses in small towns where they are one of the major employers, many of these interests overlap. Benefits of a pollution prevention project may affect relationships with these groups in different ways, as detailed in some of the other issues (public image, employee health and safety, market share). Generally, most firms place importance on the value of being recognized as a good neighbor.

Employee health and safety. Improving working conditions can have substantial short and long-term benefits, including lower worker compensation rates due to safer conditions, lower health care payments, increased productivity, and reduced absenteeism.

Pro-active environmental strategy. Environmental regulations in Egypt and elsewhere show a clear trend toward increasingly stringent limitations for contaminations in air emissions, wastewater, and solid waste. Companies that incorporate these anticipated tougher levels in their strategic planning will have advantages over those companies that continue to avoid the requirements. Pollution prevention projects have the ability to position a company to meet or surpass projected future toxic use and discharge limits. A strong argument for a pollution prevention project is its capacity to alleviate such unknown factors as purchase price, waste disposal costs, or new health issues, that accompany the use of substances known to be environmentally damaging.

Financial liability. Financial liability can be associated with storage, transportation, and disposal of wastes; property damage associated with the misuse of wastes or materials; civil actions; or fines or penalties imposed by government entities. Although reducing liability can be one of the most significant advantages of a pollution prevention project, this benefit is usually difficult to characterize and thus may be "underweighted" in a project assessment.

Companies, environmental consultants, the academic community, and others have developed a variety of methods that attempt to characterize potential liability risk. These range from precise projections of financial exposure based on historical data of actual occurrences to current efforts to use fuzzy logic to translate managers' qualitative responses into quantitative assessments. As no method has gained wide acceptance and many are complex and require considerable time and expertise to employ, it is beyond the scope of this chapter to describe their design or use in detail.

4.6 CONCLUSION

The key point to remember is that firms are in business to make a profit, and pollution prevention can be critical to profitability. In the past, environmental expenditures were seen as pure cost sinks with no payback potential. It is becoming apparent that in the realm of pollution prevention there are a number of areas where expenditures can be cut significantly. One study of waste reduction projects showed that in 29 cases that included data on payback period, over 80% had payback periods of less than 3 years.

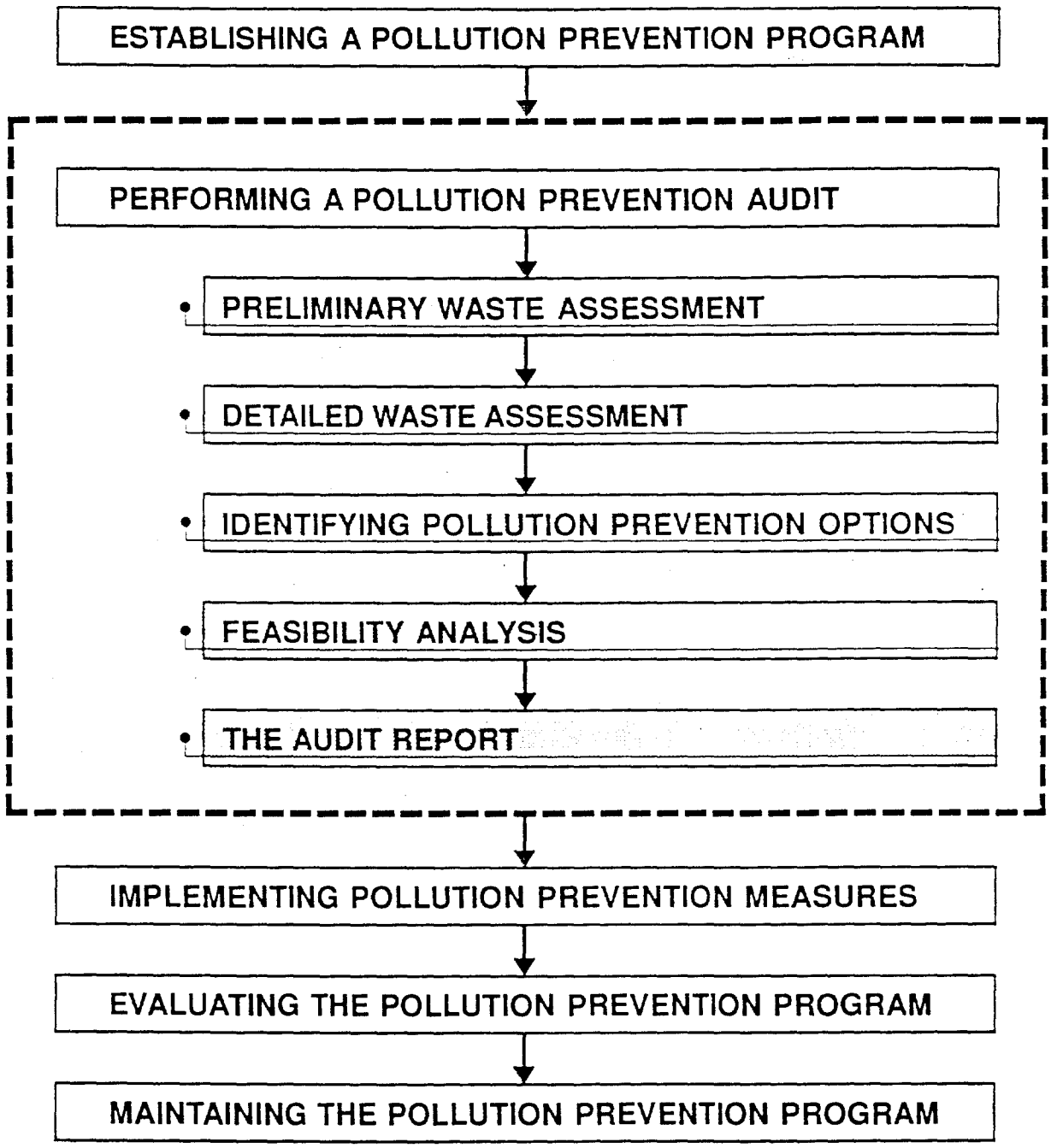
There is no doubt that environmental management can make a difference in reducing accompany's expenses. The task becomes one of selling improvements in the expense side of the profit equation. Reducing an expense is as effective as increasing revenues when it comes to profit.

The final considerations in justifying pollution prevention investments are the Tier 2 and 3 intangible costs. Many types of projects can affect revenues, expenses, and/or cash flow, but pollution prevention projects are relatively unique in their additional positive effects. Although difficult to express in concrete financial terms, both environmental compliance and pollution prevention can have far ranging benefits in terms of reduced long term liability, customer relations, public goodwill, and employee morale. While these factors may not serve to justify the investment in a project by themselves, they must enter into the analysis.

This chapter has introduced the basic financial tools and described a preference for using Net Present Value as an appropriate method of financial comparison. Suggestions were made on what types of costs should be considered in evaluating pollution prevention projects, and how those costs should be calculated over the project lifetime. An example case study using an industrial process and two pollution prevention options illustrated the key concepts presented in the chapter. Finally, the financial results of the case study were evaluated and the meaning of those results was discussed.

In conclusion, this chapter presents financial tools and a suggestion of other less tangible benefits which can be used to justify pollution prevention projects on an equal basis with other funding requests.

THE AUDIT REPORT


ESTABLISHING A POLLUTION PREVENTION PROGRAM
PERFORMING A POLLUTION PREVENTION AUDIT
• PRELIMINARY WASTE ASSESSMENT
• DETAILED WASTE ASSESSMENT
• IDENTIFYING POLLUTION PREVENTION OPTIONS
• FEASIBILITY ANALYSIS
• THE AUDIT REPORT
IMPLEMENTING POLLUTION PREVENTION MEASURES
EVALUATING THE POLLUTION PREVENTION PROGRAM
MAINTAINING THE POLLUTION PREVENTION PROGRAM

THE AUDIT REPORT

PURPOSE : Summarize the results of the audit to serve as a basis for implementing Pollution Prevention measures.

- The report can be used for:
  - Providing a schedule for implementation actions
  - Securing internal/external funding
  - Building support for the plan
  - Evaluating and maintaining the program

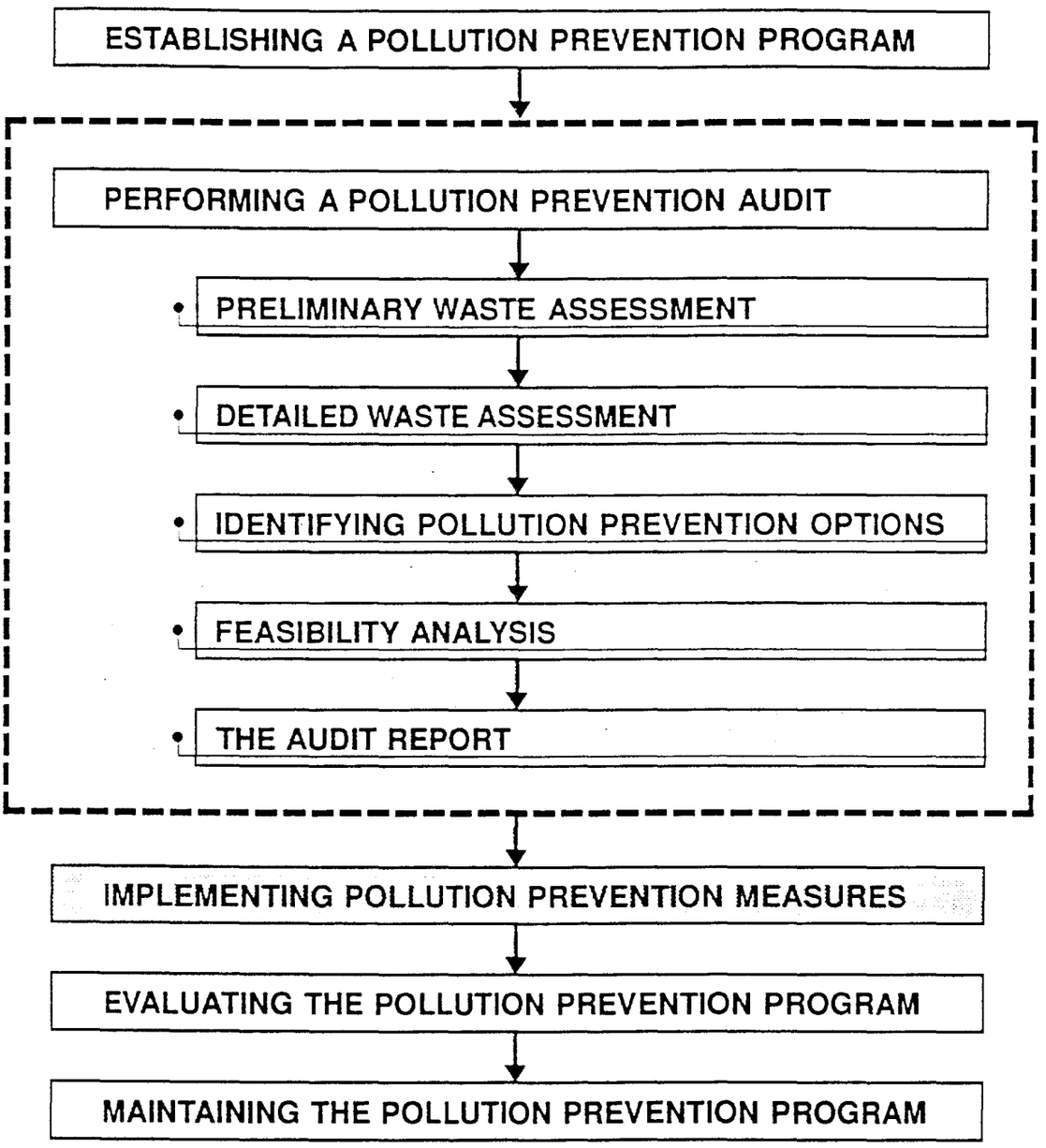
THE AUDIT REPORT

ITEMS TO BE INCLUDED IN THE REPORT

- Results of the audit
- Options proposed
- Results of option screening
- Results of feasibility anaylsis
- Project proposal for each selected option
- Estimated time for installation and start-up
- Performance measures to evaluate the project after implementation

4.

IMPLEMENTING POLLUTION PREVENTION MEASURES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IMPLEMENTING POLLUTION PREVENTION MEASURES

PURPOSE : Move forward toward realizing Pollution Prevention progress by installing the selected improvement projects.

- Select options for implementation
- Identify coordinator to carry out the projects
- Obtain funding
- Carry out general steps for any capital improvement project (e.g. planning, design, procurement, construction, and operator training
- Convince those who must work to new procedures that the change in philosophy from end-of-pipe treatment to pollution prevention makes sense and serves to improve efficiency
- Use posters around the site to emphasize the importance of Pollution Prevention and waste reduction (e.g. costs, health and safety, efficiency)
- Devise a schedule (take into account time for personnel to adjust to new protocols)
- Set up a monitoring program alongside the Pollution Prevention program to measure improvements

Pollution Prevention and Environmental Studies

NATIONAL POLLUTION PREVENTION CENTER FOR HIGHER EDUCATION

Cultural Barriers to Behavioral Change:

General Recommendations and Resources for State Pollution Prevention Programs

A Report to the U.S. Environmental Protection Agency Under Grant #XB19192-01-0.

By Dale Jamieson and Klasina VanderWerf,
Center for Values and Social Policy,
University of Colorado, Boulder

CULTURAL BARRIERS TO BEHAVIORAL CHANGE:

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by

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The views expressed in this report are solely those of the authors and should not be attributed to any of the sponsoring organizations.

PREFACE

This report has grown out of many years of thought and discussion about how cultural values affect environmental behavior. We have learned a great deal from many people who cannot all be acknowledged here. However, we would especially like to thank , who helped to conceive this project and has been instrumental in carrying it out;) and . (University of) who ably served as project advisors; (University of) and (University of) for their extensive comments on earlier drafts of this report; and and for their work in producing the final document. Finally, we would like to gratefully acknowledge the support of the late , whose work on attitude and behavior change inspired a generation of researchers and substantially contributed to making America a more tolerant and environmentally responsible society.

The first draft of this report was presented at a national/international workshop held in . This discussion among a diverse group of government officials and academics was one of the most stimulating in which we have ever participated. We learned a great deal from the workshop, some of which we are still assimilating. During the Spring of 1993 we had the opportunity of presenting our findings at a meeting of the and at a state pollution prevention conference organized by . This report is immeasurably better because of these experiences.

This report builds upon and synthesizes the work of a large number of researchers, government officials, and activists whose work contributes to preventing pollution. Perhaps the greatest single benefit that we hope this work produces is to make this community more self-conscious, and to stimulate further work in exploring and resolving cultural barriers to pollution prevention.

July, 1993

EXECUTIVE SUMMARY

In this report we discuss cultural barriers and incentives to pollution prevention behavior and make recommendations to state and other pollution prevention programs on how to address cultural barriers and incentives. Cultural barriers such as beliefs, desires, emotions, attitudes, values, mental models, and patterns of reasoning can be as powerful in inhibiting pollution prevention behavior as physical, institutional, technological, or legislative barriers. Likewise, changing beliefs, values, attitudes, and other cultural barriers can play an important role in facilitating pollution prevention behavior.

Although there are many pollution prevention programs at the state and local levels, many of these programs are not as effective as might be hoped. Programs that simply provide information to producers and consumers are often ineffective and sometimes even counterproductive. In some cases such programs may reinforce values, attitudes, and behaviors that must be changed if we are to prevent pollution.

The purpose of this report is to survey what is known about cultural barriers and incentives to pollution prevention, to make some tentative recommendations, and to set an agenda for future research. We review literature from several different disciplines including psychology, sociology, economics, and philosophy. While enough is known to identify some barriers and facilitators as well as to make general recommendations, important gaps in our knowledge remain. Furthermore, substantial difficulties are involved in bringing different areas of academic and other professional expertise into conversation with one another.

Pollution prevention has risen in importance as it has become increasingly clear that human activity is bringing about many local and global environmental changes that are detrimental to humans and other living things. Thus far, however, most of our efforts have been directed toward trying to ameliorate or reverse what has

already been done. These clean-up efforts are helpful, but they are not sufficient to address the extent and magnitude of our current problems, particularly because they do not address the long-term challenges posed by environmental change. What is needed is a vision of a sustainable future, and some sense of how to get there from here. Individuals, businesses, and government will all have to share the burden of this transition. Indeed, if pollution prevention is to succeed over the long term, it must increasingly be seen not as a burden, but as a way of life voluntarily chosen and willingly embraced.

Pollution is, in part, a behavioral problem, and behavior can be extremely difficult to change. Yet a change in behavior will be necessary if long-term environmental goals are to be met, and it will surely also be accompanied by cultural changes that involve significant shifts in values. A fundamental shift in focus needs to occur. Rather than seeing the environment as something external to us that it is the responsibility of environmental professionals to maintain, we must focus on seeing ourselves as situated in an environment which it is our responsibility to preserve. Prevention approaches focus on a sense of obligation and responsibility.

The prevention approach to pollution problems is gaining attention because we have come to recognize that our current efforts don't provide a complete solution to the problem. Although the current strategy of "command and control" has proven valuable in dealing with pollutants once they are created and in the system, it does not address preventing the creation of pollutants in the first place. Pollution prevention provides us with the other critical tool necessary for dealing with the problem of pollution. It can also prove valuable by creating a solution which has the commitment and investment of all those involved and which instills the kind of individual behavior and sense of responsibility on which long-term environmental protection is built.

The incorporation of a pollution prevention approach will not be without difficulty. Many barriers and difficulties stand in the way of implementation--the pollution prevention approach places

values must be sensitive to charges of manipulation and exploitation. Thus, it is important in the implementation of pollution prevention programs to respect people as active information processors and knowledge-users. Indeed, if long-term success rather than merely the short-term modification of behavior is to be achieved, it is vital that people's values, beliefs, and reasoning become more reflective, and this requires treating them with respect. Thoughtful, reflective citizens are more likely to produce long-term sustainable change than those whose motivations and concerns are short-term. It is also important to recognize that pollution prevention does not require a radical revision of everyday values. Surveys show that environmental values are strongly held by many Americans. For many people the strongest motivator for pollution prevention will be concerns for children and community, values already deeply rooted in American life.

The literature we have surveyed regarding cultural barriers to pollution prevention comes from a wide variety of disciplines. Consequently there is some fragmentation of information, and often wide diversity in methods, use of concepts, and structure of models. Because of these gaps in the available literature, we have found that the best way to use it for policy purposes is to read it suggestively. Much of the literature is quite rich when approached in this way.

Our literature review covers studies that have employed four basic methods: surveys, behavioral experiments, ethnographic interviews, and the synthetic-analytic approach. These different methods employ various usages of key concepts and words. In an effort to simplify the use of concepts across the various disciplines and methods, we identify seven factors that affect behavior: beliefs, desires, attitudes, values, emotions, patterns of reasoning, and mental models. Depending on how these factors are functioning, they can either facilitate behavioral change or act as a barrier to it. While these concepts apply most naturally to individuals, they also apply to institutions and collectives.

Beliefs, desires, and emotions are most immediately connected

great demands on all actors including government, business, and consumers for greater knowledge about the effects of their actions, common tools of measurement and evaluation, and coordination of efforts toward a common goal. Yet despite these difficulties, the potential of adding pollution prevention to the tools that we already have is so great that it is important to pursue it.

State pollution prevention programs could make a difference over the long term in a number of different areas, including production and consumption of toxics, consumer products, energy use, climate stabilization, and pollution prevention education. But first it is important to have a clear understanding of what pollution prevention is. We can generally distinguish two types of pollution prevention behavior. One kind is directed toward reaching some existing goal by employing alternative means that produce less pollution. Another kind involves actually shifting our goals.

Since pollution prevention bears on many different yet often overlapping issues, a successful program must be "multi-media"--it cannot rely on a single method or approach. Additionally, in order to be maximally effective, pollution prevention programs must touch the lives of all citizens. Thus, various cultural barriers and facilitators must be addressed if pollution prevention behavior is to become the norm. Bringing about long-term, sustainable change toward pollution prevention involves understanding the cultural beliefs, desires, emotional responses, attitudes, values, patterns of reasoning, and mental models that sustain present behavior. Despite the importance of cultural barriers to pollution prevention, of all the barriers they are the least understood, because they are complex, and they are often neglected or overlooked. Overcoming these barriers is key to successfully implementing a prevention program.

One of these cultural barriers concerns people's values. A successful pollution prevention program depends on people coming to value efficiency and even sufficiency over excessive consumption. Yet any program whose success depends on a reorientation of basic

mental models, attitudes toward risk, and values. Next we consider the effects of the social milieu of the individual, since social norms and community expectations are clearly important in sustaining a pattern of behavior. Even if a person is not closely linked to a community, the prevailing norms and expectations may still bring the person's behavior into conformity with community values. We then look at facilitators and barriers that may affect the performance of environment-friendly actions, including a sense of efficacy, public commitment, rewards, coercion, shame and embarrassment, and personal experience. Finally, we consider four factors involved in the effectiveness of information provision: salience, utility, persuasiveness, and feedback mechanisms.

Our report contains sixteen tentative recommendations that we have developed based on what we have learned from analyzing the literature and from interviews with a variety of people active in pollution prevention. They are general recommendations, based on our research and our best guesses, and therefore intended to be used as guidelines for those who work in pollution prevention. Although they cannot be applied mechanically, they should be useful when applied with the insight and sensitivity of those who work in particular programs and who know what their own specific needs are. Our recommendations are as follows:

1) Rewards and incentives may not be as effective as values in sustaining behavior over the long-term.
2) Values that we already hold can be powerful.
3) Specific values may be more important in generating action than general values.
4) Knowing how to prevent pollution may be as important as wanting to prevent pollution.
5) How information is presented helps to determine its effectiveness.
6) The credibility of information is affected by its source.
7) New information is understood in terms of old concepts.
8) Stories, anecdotes, and analogies can be powerful resources.

with individual behavior. Values and attitudes underlie and help to generate or rationalize particular beliefs, desires, and emotions. Mental models provide the framework in which these features are embedded. Patterns of reasoning affect the perceived relationships between these elements and can also produce new beliefs or values. All of us hold beliefs that are true and also beliefs that are false. We have a multiplicity of desires, a plurality of attitudes, and a host of diverse values. Any attempt to overcome cultural barriers to pollution prevention behavior must confront the reality of our existing mental models. A number of different conceptual models for behavioral change have been employed in the literature we surveyed, but two models have been especially influential: the rational choice model and the attitude model. The basic idea behind the rational choice model is that people's behavior is determined by their interests. The attitude model supposes that people's actions are caused by underlying positive or negative dispositions toward the results of these actions. We briefly review three specific types of attitude models: a causal model of environmentally relevant behavior, a psychological-social model of energy conservation, and a decision-making model of environmental behavior.

Although the existing literature related to cultural barriers to pollution prevention behavior is strikingly uneven with respect to the problems it addresses, it is possible to summarize some basic themes: behavioral studies have focused primarily on individuals and households rather than institutions and workplaces; emphasis has been placed on relatively small day-to-day choices rather than major investment decisions; and relatively little attention has been paid to how one environment-friendly behavior may lead to others.

In our literature review, we begin by looking at some themes that have emerged about how various individual attributes may affect pollution prevention behavior. The attributes we consider are demographic factors, positional factors (reflecting one's situation, e.g., homeowner or renter), attitudes and past behavior,

mental models, attitudes toward risk, and values. Next we consider the effects of the social milieu of the individual, since social norms and community expectations are clearly important in sustaining a pattern of behavior. Even if a person is not closely linked to a community, the prevailing norms and expectations may still bring the person's behavior into conformity with community values. We then look at facilitators and barriers that may affect the performance of environment-friendly actions, including a sense of efficacy, public commitment, rewards, coercion, shame and embarrassment, and personal experience. Finally, we consider four factors involved in the effectiveness of information provision: salience, utility, persuasiveness, and feedback mechanisms.

Our report contains sixteen tentative recommendations that we have developed based on what we have learned from analyzing the literature and from interviews with a variety of people active in pollution prevention. They are general recommendations, based on our research and our best guesses, and therefore intended to be used as guidelines for those who work in pollution prevention. Although they cannot be applied mechanically, they should be useful when applied with the insight and sensitivity of those who work in particular programs and who know what their own specific needs are. Our recommendations are as follows:

1) Rewards and incentives may not be as effective as values in sustaining behavior over the long-term.
2) Values that we already hold can be powerful.
3) Specific values may be more important in generating action than general values.
4) Knowing how to prevent pollution may be as important as wanting to prevent pollution.
5) How information is presented helps to determine its effectiveness.
6) The credibility of information is affected by its source.
7) New information is understood in terms of old concepts.
8) Stories, anecdotes, and analogies can be powerful resources.

9) It is generally more effective to work through existing communities or groups than to build new ones.

10) Information about the effects of our past actions influences present behavior.

11) People are more likely to act if their behavior clearly makes a difference.

12) People are more likely to act if they feel responsible for an outcome.

13) Public commitment makes people more likely to act.

14) Role models are important.

15) Change agents are important.

16) The quality of relationships matters.

Our report concludes with an outline of an agenda for future research and other work into cultural barriers and facilitators to pollution prevention behavior. Gaps in the existing literature on cultural barriers suggest that it will be important to provide definition and organization to this new field of study that incorporates such diverse disciplines. Several particular areas of research within the arena of cultural barriers also deserve more attention. For instance, although we gained insight into how values are formed in general, we lack methods for predicting value change. Future research on this topic will be necessary, as will consideration of the ethics of modifying the values of others. The role of psychological research should be emphasized as well, because pollution prevention is ultimately a matter of human behavior. It is humans who make consumer choices and energy use decisions and who can bring pressure to bear on those who pollute. To that end, we also need more specific information about how people make consumer decisions, particularly those related to capital purchases such as furnaces, cars, or refrigerators. Finally, practical considerations suggest that research on institutions as well as individuals will be necessary, and on-going analysis of existing pollution prevention activities will undoubtedly contribute to the success of any pollution prevention program.

PART I: THE PROBLEM

In this report we discuss cultural barriers and incentives to pollution prevention behavior and make recommendations to state and other pollution prevention programs on how to address cultural barriers and incentives. Cultural barriers such as beliefs, desires, emotions, attitudes, values, mental models, and patterns of reasoning can be as powerful in inhibiting pollution prevention behavior as physical or technological barriers. Likewise, changing beliefs, values, attitudes, and other cultural barriers can play an important role in facilitating pollution prevention behavior.

State governments are well positioned to help bring about the transition to a society that prevents pollution, away from one that devotes an ever-increasing share of its resources to trying to mitigate the effects of pollution. Through public information programs, outreach, technical assistance, and proactive planning, state governments can be effective agents in making pollution prevention a reality.

Although there are many pollution prevention programs at the state and local levels, many of these programs are not as effective as might be hoped. Programs that simply provide information to producers and consumers are often ineffective and sometimes even counterproductive. In some cases such programs may reinforce values, attitudes, and behaviors that must be changed if we are to prevent pollution.

The purpose of this report is to survey what is known about cultural barriers and incentives to pollution prevention, to make some tentative recommendations, and to set an agenda for future research. We review literature from several different academic disciplines including psychology, sociology, economics, and philosophy. While enough is known to identify some barriers and facilitators and to make some recommendations, important gaps in our knowledge remain. Furthermore, substantial difficulties are involved in bringing different areas of academic expertise into

conversation with one another.

Pollution prevention has risen in importance as it has become increasingly clear that human activity is bringing about many local and global environmental changes that are detrimental to humans and other living things. For example, the diminishing of the ozone layer weakens the shield that protects living things from ultraviolet radiation; the pollution of air and water poses health risks; and the production and consumption of toxic materials makes sections of our cities and states unsightly and unsafe.

Thus far most of our efforts have been directed toward trying to ameliorate or reverse what has been done. Efforts to clean up pollution can help to alleviate the situation, but they are not sufficient to address the extent and magnitude of our current problems. "End-of-pipe" regulation imposes large costs on the economy, and it cannot answer the widespread popular concern about even very small concentrations of pollutants.

Most important, amelioration efforts do not address the long-term challenges posed by environmental change. What is needed is a vision of a sustainable future, and some sense of how to get there from here. State and federal agencies alone cannot ensure this transition. For such a vision to be successfully implemented it will have to engage with people's basic values and appeal to their sense of responsibility. Individuals, businesses, and government will all have to share the burden of pollution prevention. Indeed, if pollution prevention is to succeed over the long term, it must increasingly be seen not as a burden, but as a way of life voluntarily chosen and willingly embraced.

Government regulation has an important role to play, and it is difficult to imagine a future in which it does not play a part. But the excessive use of regulation creates an atmosphere that is not conducive to long-term success. For in order to secure a sustainable future we must engage people's voluntary impulses and desires for change, and a social climate characterized by government coercion is inhospitable to these impulses and desires. As a nation we must make reflective choices about the level of

environmental quality that we desire and align our behavior with our considered judgments.

Clearly there will never be complete agreement across all sectors and communities about the appropriate level of environmental quality. But we must move beyond the present situation in which conflicts arise not just between people, but also within people. Many of us desire higher levels of environmental quality, yet our behavior contributes to environmental degradation. Part of the reason for this is the work situations we find ourselves in, our lack of alternatives with respect to our consumer choices, and so on. Yet both as individuals and as a society we must do more to reconcile our values and our behavior, and our beliefs and our actions.

Pollution prevention strategies and policies can make an important contribution in securing long-term environmental success. State programs in particular, because they can reflect regional choices and values and serve as laboratories for experimentation, have the potential to be on the cutting edge of pollution prevention. However, it will not be easy for state pollution prevention programs to define their roles and to carry them out successfully. Pollution is, in part, a behavioral problem, and behavior can be extremely difficult to change. Yet if long-term environmental goals are to be met, changes in behavior must occur. If new environment-friendly patterns of behavior are to be stable and enduring, they must be accompanied by cultural changes that involve significant shifts in values.

A. A PREVENTION APPROACH

Prevention is a major goal in various areas of human life. As a society we have come to see that prevention is the best solution for various health problems such as cancer and heart disease. At a personal level most of us recognize that preventive maintenance for our cars and homes is a good strategy. The focus on prevention brings with it a sense of obligation and responsibility. In order for many public health programs to be successful, people must come to feel responsible for their own health. Instead of seeing their

bodies as machines that it is the job of health professionals to maintain, they must come to see themselves as embodied, with the responsibility to do what they can to keep themselves healthy.

Like these other prevention approaches, pollution prevention requires a fundamental shift of focus. Rather than seeing the environment as something external to us that it is the responsibility of environmental professionals to maintain, the pollution prevention approach focuses on seeing ourselves as situated in an environment which it is our responsibility to preserve.

A prevention approach to pollution is gaining attention because of the widespread perception that our current efforts at environmental protection are failing. Many people argue that our current patterns of resource use are inconsistent with global equity and also deprive future generations of what should be their birthright. Moreover, while non-renewable resources appear to be in good supply, pollution generated from human activity increasingly threatens renewable resources such as air, water, soils, biodiversity, ozone, and climate.

In addition to these large-scale concerns, many people believe that our "command and control" approach to environmental protection isn't a complete solution to the problem. Pollution prevention is the other part of the solution. While command and control can be effective in dealing with pollutants that are already in the system, we need in addition to seek a solution that attempts wherever possible to eliminate the creation of the pollutants in the first place.

Command and control has been criticized because it imposes an adversarial model on environmental regulation, thereby driving out "win/win" alternatives. It has also been criticized because it can foster a minimal commitment, that is, encouraging people to do only what is absolutely necessary to meet standards and no more. And command and control has been further critized because it locates the responsibility for dealing with pollution with the government and with business rather than encouraging the individual behavior

and sense of responsibility on which long-term environmental protection is built.

Despite the difficulties involved in moving to a pollution prevention focus, such an approach has much to recommend it. Actions that prevent pollution can have a greater impact than actions that try to mitigate a problem which already exists. For example, purchasing a fuel-efficient car will contribute less to pollution than the careful maintenance of an inefficient vehicle, and cutting back on packaging can do more for waste reduction than recycling paper. Moreover, many of the problems that result from human activity, such as the release of chlorofluorocarbons, are difficult if not impossible to control once they have been set in motion. Controlling pollution at its source is often much more effective than responding once it has become diffuse.

Generally across the economy, a pollution prevention approach makes good economic sense and will contribute to competitiveness and stimulate new business opportunities. Both international and domestic experience shows that pollution prevention and economic growth can go hand-in-hand. In many cases, it is cheaper to prevent pollution than to clean it up. Over the long term many of the strategies involved in pollution prevention programs will lead to more efficient and effective use of resources, thus contributing to both economic and national security and sustainability. This does not mean, however, that all facilities, sectors, and regions will benefit equally from pollution prevention. Changes of policy and focus always create winners and losers, even if only in positional terms. Not every facility in every industry will survive in a pollution prevention environment.

Perhaps the most important reason for adopting a pollution prevention approach is that it has the potential to provide a central organizing principle for our environmental protection efforts. These efforts have often been fragmented across various divides: single-medium programs are often not coordinated with each other; regulatory agencies at different levels of government often make different, even inconsistent, demands; the culture of

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enforcement often seems contradictory to the culture of problem-solving.

The pollution prevention approach provides an opportunity for dealing with these problems in a consistent way. By providing a common focus for environmental protection efforts, it can establish common ground on which to negotiate these divisions. However, it would be foolish to expect these divisions to disappear entirely. To some extent they are established by legislation and nourished by history and tradition. At the same time the pollution prevention approach presents us with our best opportunity for overcoming these divisions.

At this stage, however, pollution prevention should be thought of as a vision for the future rather than a policy of the present. If pollution prevention were easy to implement it would already be in place either through the magic of the market or through administrative directive. Many barriers and difficulties need to be overcome. The pollution prevention approach places great demands on all actors including government, business, and consumers for greater knowledge about the effects of their actions, common tools of measurement and evaluation, and coordination of efforts toward a common goal. Yet despite these difficulties, the potential of pollution prevention is so great that it is important to pursue it.

B. SOME KEY POLLUTION PREVENTION ISSUES

State pollution prevention programs could make a difference over the long term in a number of different areas, including production and consumption of toxics, consumer products, energy use, climate stabilization, and pollution prevention education. Before discussing these areas, it is important that we have a clear understanding of what pollution prevention is.

Pollution prevention means different things to different people. To some people it is a fashionable buzzword with little content; to others it is a new set of demands and responsibilities piled on top of others that are themselves barely manageable. In practice, for many people, pollution prevention means getting

businesses to reduce their use of toxic materials.

In addition to these understandings of pollution prevention, this term is also defined in the federal Pollution Prevention Act of 1990, in subsequent US EPA policy statements, and in legislation passed in more than half the states. US EPA's definition of pollution prevention includes source reduction and any other practices that reduce or eliminate the creation of pollutants through increased efficiency or conservation. Source reduction is any practice that reduces the amount of any hazardous substance, pollutant, or contaminant that is released into the environment, or reduces the hazards to public health and the environment associated with the release of such substances. A broad definition of pollution prevention includes recycling because it is an activity which avoids the creation of new pollutants. Definitions in state legislation are narrower in some cases and broader in others.

We can generally distinguish two kinds of pollution prevention behavior. One kind of pollution prevention behavior is directed toward reaching some existing goal by employing alternative means that produce less pollution. Examples of pollution prevention behavior of this type include replacing toxic solvents with nontoxic ones, reducing packaging, using energy-efficient light bulbs, bicycling instead of driving, and carrying a cup to work. Another kind of pollution prevention behavior involves shifting our goals. For example, telecommuting may not be a perfect substitute for commuting. Contact by fax or telephone is not the same as face-to-face interaction. Yet telecommuting may serve enough of the purposes of commuting to make it a feasible alternative, and it may also open up other possibilities that may help us to realize other goals (e.g., by permitting us to work at home, and so on). Similarly, avoiding the use of toxic lawn chemicals may require us to grow different plants.

The areas identified as pollution prevention target areas for the purposes of this report overlap in various ways. For example, programs that promote energy efficiency contribute to climate stabilization by reducing emissions of carbon dioxide. Reducing

packaging of household products may help to minimize consumption and production of toxic materials. Furthermore, pollution prevention education is important to making gains in all of these areas.

Before discussing some of the key concepts involved in thinking about cultural barriers to pollution prevention, we will briefly discuss these five areas of concern.

1. The Production and Consumption of Toxics

One important target of pollution prevention programs is the production and consumption of toxics. Although we need to reduce the production of toxics and also provide consumers with effective alternatives for the toxics that are now in use, this issue may be overemphasized relative to other pollution prevention issues. This may be a result of the fact that pollution prevention programs are often housed in offices whose main charge is the regulation of toxics, and they are often funded by fees and penalties assessed on producers who use toxic materials. The use of toxics is a tempting target for those who are interested in pollution prevention because there are a relatively small number of large actors in this area about whom quite a lot is known due to various reporting requirements. It is important to remember, however, that not all pollution prevention problems have this profile.

One problem that arises when considering the question of toxics concerns its definition. Scientists, regulators, and industry may all have different views about whether or not a particular product should be considered toxic. In addition to definitional differences, the toxicity of many materials is a matter of great uncertainty. Moreover, people have different attitudes toward this uncertainty. Toxicity is probably best thought of as a matter of degree; but here again, people differ about the degree of risk that they regard as acceptable. To some extent a pollution prevention perspective helps us to cut through these problems: it makes sense to reduce the use of any material, however toxic, whenever possible.

Materials that are to some extent toxic occur in a wide range

of household products. For example, metals such as cadmium, lead, and mercury are used in batteries, pigments, plastics, and paints. Toxic organic substances include solvents, petroleum distillates, and volatile organic compounds that are used in cleaners, lubricators, paints, varnishes, plastics, dyes, and pigments. Acids and alkalies are found in such common household products as bleaches and cleaners.

The production and consumption of toxics pose a range of societal problems. They present issues both with respect to worker safety and safe household use. There are also well-publicized difficulties in disposing of toxic materials. Although people use these materials, they do not readily accept living near disposal sites. Pollution prevention programs have the potential to minimize these problems by reducing the amount of toxic material that is produced and consumed.

2. Consumer Products

Consumer products is an area with a great deal of pollution prevention potential. Tracing the life cycle of a product from production to disposal demonstrates the range of problems that can result from consumer products. Extractive industries that make available the raw materials for consumer products are associated with many environmental problems. Mineral extraction is associated with problems of air and water quality and often leads to toxic residues. Logging often creates ecological problems and threatens other resources such as fisheries. Fabrication processes pose problems in many different areas. After a product has worn out, been exhausted, or fallen from favor it is dubbed "garbage," and becomes a problem for waste disposal.

In recent years problems of waste disposal have gotten a great deal of attention. It is becoming increasingly difficult for communities to find adequate waste disposal sites, even when the waste is not classified as hazardous. Alternatives to landfills such as incinerators have engendered a great deal of resistance. Yet according to reports of the Organization for Economic Cooperation and Development, the per capita waste generation of

Americans, and indeed most people in the industrialized world, continues to increase. The pressures of waste disposal are felt by people in various areas of their lives, ranging from litter in their communities to higher taxes and fees to fund the creation of new waste disposal sites.

Reuse and recycling are two approaches to these problems associated with consumer products. Many products can be efficiently recycled, requiring significantly fewer environmental inputs than the fabrication of a replacement product. For example, a recycled aluminum can be produced with about one-third of the energy investment of a new can. A reusable glass bottle can be used 40-50 times for the energy investment required to manufacture a replacement. But there are serious difficulties in the economics of recycling, and many consumer products cannot be recycled at all. Although experiments in recycling such products as automobiles are currently underway, prevention is a simpler and more effective approach if it can be put into practice.

Packaging reduction is one obvious target for pollution prevention programs. Since 1990 McDonald's has been working with the Environmental Defense Fund to reduce waste. This campaign appears to be successful in several ways: McDonald's is taking significant steps to reduce waste; by demonstrating their commitment to waste reduction, McDonald's has gained public relations benefits; finally, the efforts McDonald's has been making have contributed to educating its employees, suppliers, and customers about pollution prevention.

More generally, the use of reusable shopping bags, bulk purchasing, and packaging reduction shows that our purposes as consumers can be just as well served with fewer environmental inputs. However, in the long term it may be necessary to go beyond programs that take our present goals as fixed. Consumer products are a means to quality of life and fulfillment, not ends in themselves. We need to begin thinking about how quality of life can be improved with fewer environmental inputs.

3. Energy Use

The use of energy entails many different environmental problems. The use of fossil fuels such as wood, coal, and oil produces large amounts of atmospheric pollution that are difficult and expensive to control. Pollutants that result from the combustion of fossil fuels cause respiratory and cardiovascular problems in humans, degrade visibility, and may contribute to climate change. These pollutants are also implicated in the production of acid precipitation which has deleterious effects on ecosystems and materials. Nuclear power generation is regarded as unacceptably unsafe by many people and creates problems of waste disposal that have not yet been solved. Even "renewable" energy sources such as solar, wind, and hydroelectric generation create visual or noise pollution and sometimes have undesirable ecological effects.

Energy efficiency is central to pollution prevention since using less energy is the most effective way of reducing the pollution that results from its use. Many effective programs that encourage energy efficiency are currently in place. The EPA's "green lights" program has had an important effect on business, and some local utility companies have mounted aggressive campaigns that include subsidies for residential insulation and the use of energy efficient lighting sources. Innovative pricing structures have also helped to reduce peak demand. New cars and appliances are in most cases much more energy efficient than those they replace, and stickering programs help consumers to make informed decisions.

Yet despite these gains, much remains to be done in reducing the use of energy. While the United States is now producing more economic benefits from less energy consumption than it was two decades ago, these gains are relative and not absolute: American energy consumption continues to rise. We continue to have a more energy-intensive economy and society than almost any other country. The potential for further efficiency gains is very great. However, changes in life-style may be required to realize some of these gains.

As we shall discuss in Part II of this report, energy

efficiency is an area that has received a great deal of attention. Faced with the same economic incentives, different people sometimes respond in very different ways. We are challenged in the pollution prevention area both to produce greater gains in energy efficiency and also to see how what is known about energy use can be transferred to other areas with pollution prevention potential.

4. Climate Stabilization

In recent years concern has mounted about the possibility of anthropogenic climate change. Many scientists believe that emissions of such gases as carbon dioxide, methane, and chlorofluorocarbons caused by human activity have the potential to bring about a dramatic change of climate in a relatively short period of time. If such climate change occurs it will have serious effects on wilderness and endangered species, on the fabric of international relations, and on the American economy and way of life.

The issue of climate stabilization is complicated, but it is clear that pollution prevention activities have a role to play in reducing the risk of climate change. One of these areas has already been discussed. If we succeed in reducing our production and consumption of fossil fuels, then the threat of climate change will to some extent diminish. Further, a general pollution prevention focus that seeks to produce greater quality of life from fewer environmental inputs and outputs is likely to contribute to climate stabilization. At this stage climate stabilization perhaps is best seen as a welcome secondary effect of other pollution prevention activities. Over the long term, however, the possibility of climate change could well have a dramatic effect on how we organize our economy and society.

5. Pollution Prevention Education

Pollution prevention education is an important concept that underpins efforts in all four of the other areas. If pollution prevention is to be successful, people will need to be effectively educated about toxics, consumer products, energy, and the risk of climate change. Moreover, they will need some basic competence

with respect to the pollution prevention concepts that underlie all of these specific concerns. In this respect pollution prevention education must be holistic and comprehensive, focusing on the systemic sources of pollution and how they can be addressed.

Education can be considered in both a broad and narrow sense. In the broad sense education permeates all areas of our lives. Education occurs when we talk to friends and neighbors, watch television, and learn from experience. In this broad sense almost every pollution prevention program can be thought of as having an educational dimension.

Education in a narrower sense is what occurs in such institutions as schools and colleges. Although in recent years environmental education has become more prominent in educational institutions, the goal of pollution prevention challenges us to reform curricula and even to rethink some of the basic concepts of education. There are some recent attempts to do this in higher education, coordinated by the National Pollution Prevention Center for Higher Education at the University of Michigan.

Education both broadly and narrowly construed can be either declarative or procedural. Declarative education focuses on teaching students what is the case. It involves knowledge that is primarily propositional in form--the sort of knowing that in the philosophical literature is called "knowing that." Procedural knowledge focuses on teaching students how to do things. It is directed toward giving students the behavioral competence to undertake specific tasks. In the philosophical literature this sort of knowing is referred to as "knowing how." Both kinds of education are important for pollution prevention. Shifts in beliefs, values, attitudes and so on require propositional knowledge; but acting on this knowledge requires behavioral skills and competencies.

Pollution prevention education can take many specific forms. In one form it may consist in making available to students information that will make them aware of alternatives to everyday pollution producing activities. For example, pollution prevention

education may teach students about composting as an alternative to disposing of organic wastes in landfills. This kind of education can be useful, but its effectiveness is limited by many of the difficulties that face public education campaigns in general (see Part II.B.3).

A second form of pollution prevention education may directly address the cultural barriers that we discuss in this report. Students may specifically learn about various obstacles to the employment of pollution prevention technologies and practices. By making students aware of these obstacles, we may hope to overcome them. For example, once students learn that they tend to systematically underestimate the amount of waste they produce, they may become more conscious about household waste and do a better job of reducing it.

A third form of pollution prevention education is the most challenging. Orr (1992) notes that while the importance of literacy and numeracy are emphasized in our educational systems, the idea of "ecological literacy" has yet to take hold. We might think of ecological literacy as competence in understanding the environmental effects of our actions. An ecologically literate person would be one who associates with each commodity that he or she consumes all of its environmental effects from its production to its disposal. For example, an ecologically literate person would understand both the short-term and long-term environmental consequences of burning one gallon of gasoline when deciding what kind of car to buy.

Ecological literacy is a challenging ideal because rather than being an additional goal or area of study, it suggests a systematically different approach to education. Ecological literacy might be taught in conjunction with history, art, or mathematics. Indeed the very functioning of a school could well provide a lesson in ecological literacy. With the help of teachers, students could research both the sources and effects of the energy that powers the school; the life-cycle of the food that is served in the cafeteria could be studied along with the systems

that bring water to the school and dispose of it as waste.

Because pollution prevention is so closely associated with how we live our lives, many exciting pollution prevention programs can be undertaken in the schools, ones that employ "hands-on" techniques that may produce lasting effects on students. Indeed, many very good educational programs are already in place. These programs have an important role to play in addressing pollution prevention. Despite their potential benefits, pollution prevention programs face some unique and extremely complex problems. An understanding of these problems helps to explain why historically there has been a lack of attention to source reduction and other pollution prevention measures. Since pollution prevention bears on many different issues ranging from energy consumption to the production and consumption of toxic materials, a successful program must be "multi-media"; it cannot rely on a single method or approach. In order to be maximally effective, state pollution prevention programs as well as those at other levels of government must touch the lives of all citizens. Every producer and consumer is a pollution prevention actor.

C. CULTURAL BARRIERS AND FACILITATORS

Various cultural barriers must be addressed if pollution prevention is to become the norm. New pollution prevention technologies will do little good if people do not use them. "Getting the prices right" is part of the solution, but in some areas people have shown remarkable resistance to change even in the face of shifting economic incentives. Moreover, it is unlikely that we will systematically restructure our economy so that it rewards pollution prevention behavior unless pollution prevention comes to be something that people strongly value.

Discussions often polarize between those who believe that in order to achieve pollution prevention corporate and governmental institutions must change, and those who believe that the burden is on individuals to change their values and behavior. We believe that this is a false dilemma. In order for institutions to change, individuals will have to make new demands upon them. Individuals

are more likely to change their values and behavior in a sympathetic institutional environment.

Bringing about long-term, sustainable change toward pollution prevention involves understanding the cultural beliefs, desires, emotional responses, attitudes, values, patterns of reasoning, and mental models that sustain present behavior. It is in these areas that cultural barriers to pollution prevention in both individuals and organizations can be found. It is important to remember, however, that what is a barrier from one point of view can be, from another perspective, a facilitator. For example, if a bias toward the "near and dear" is identified as a barrier to adopting a pollution prevention perspective, then from another point of view this presents a challenge to design programs which exploit this psychological tendency on behalf of pollution prevention.

Cultural barriers to pollution prevention exist in government, business, and in American culture as a whole. Government agencies are typically regulatory, reactive, and single-medium focused rather than cooperative, proactive, and holistic in their outlook. History, tradition, reward structures, organization, and bureaucratic inertia may all contribute to resisting change. Similar barriers exist in the private sector. In addition, the pressure to satisfy regulators, managers, and stockholders can create an atmosphere which discourages innovation that does not immediately improve the bottom-line. Moreover, the pollution prevention community tends to focus on government and business to the exclusion of concerns about the general public. Yet, ultimately, changes in government and business will be closely associated with changes in popular outlook.

Shifts in these cultural barriers and facilitators have the potential for enabling enduring and comprehensive changes in patterns of human action. Despite their importance, of all the barriers confronting pollution prevention programs, cultural barriers are the least understood. Although they are complex, neglected and overlooked, overcoming these barriers is key to implementing a pollution prevention approach.

D. VALUES AND RESPONSIBILITY

Pollution prevention programs must overcome various cultural barriers if they are to be successful. One of these barriers concerns people's values. A successful pollution prevention program depends on people coming to value efficiency over excessive consumption, and its long-term success may even depend on people coming to value sufficiency over efficiency.

Any program whose success depends on a reorientation of basic values must be sensitive to charges of manipulation and exploitation. Governments and other powerful institutions have opportunities to create events and shape messages in misleading and manipulative ways. In implementing pollution prevention programs it is important to respect people as active information processors and knowledge users. People should not be viewed as laboratory animals to be manipulated in order to obtain some desired result. Indeed, if long-term success rather than merely the short-term modification of behavior is to be achieved, it is vital that people's values, beliefs, and reasoning become more reflective, and this requires treating them with respect. It is also important to recognize that pollution prevention does not require a radical revision of everyday values. Surveys show that environmental values are strongly held by many Americans. For many people the strongest motivator for pollution prevention will be concerns for children and community, values already deeply rooted in American life.

Rather than being autonomy-threatening, pollution prevention programs that have a long-term focus can contribute to people's autonomy and sense of responsibility. Many environmental problems have the character of collective action problems--widespread deleterious effects are brought about unintentionally by the tiny contributions of a great many people. Such problems occur in part because people feel alienated from their communities and the consequences of their actions; they persist because people feel powerless to change them. Pollution prevention strategies have the potential to empower people. People who are empowered are more

likely to see themselves as responsible actors. When people see themselves as responsible actors they are more likely to make a difference. For this reason a non-coercive pollution prevention approach has practical as well as moral value. Thoughtful, reflective citizens are more likely to produce long-term sustainable change than those whose motivations and concerns are short-term.

PART II: A SURVEY OF THE LITERATURE

From one perspective, it can be said that the literature that relates to cultural barriers to pollution prevention is overwhelming; from another perspective it is sparse. Researchers from a wide variety of disciplines have done work that may be thought to bear on some aspect of our problem, but very little work has been done that is directly focused on cultural barriers to pollution prevention. In these circumstances a review of the literature is inevitably impressionistic. Different researchers would probably emphasize different aspects of the literature. It would be foolish to expect complete agreement about what is important or to expect one review of the literature to be definitive.

One approach that we have used to some extent is to look at literature that examines behavior that appears to be analogous to pollution prevention behavior. Recycling is generally not considered a core pollution prevention behavior, but we have proceeded on the assumption that important insights can be gained from looking at the literature which examines recycling. In a more limited way we have examined the literature on smoking and seat belt use. Although we believe that insights can be gained here, thus far we have been disappointed in much of what we have found.

In addition to the problem of determining exactly what literature is relevant to the project, a further problem lies in trying to synthesize the literature that has been identified as relevant. Even when questions are closely related, different researchers often focus on different aspects of problems. Concepts are used in different ways and different models are employed. These differences make it difficult to compare results directly. When the literature is read from a problem-oriented perspective, the fault lines that separate disciplines and research traditions emerge very clearly.

As a result of this fragmentation, the best way to use the

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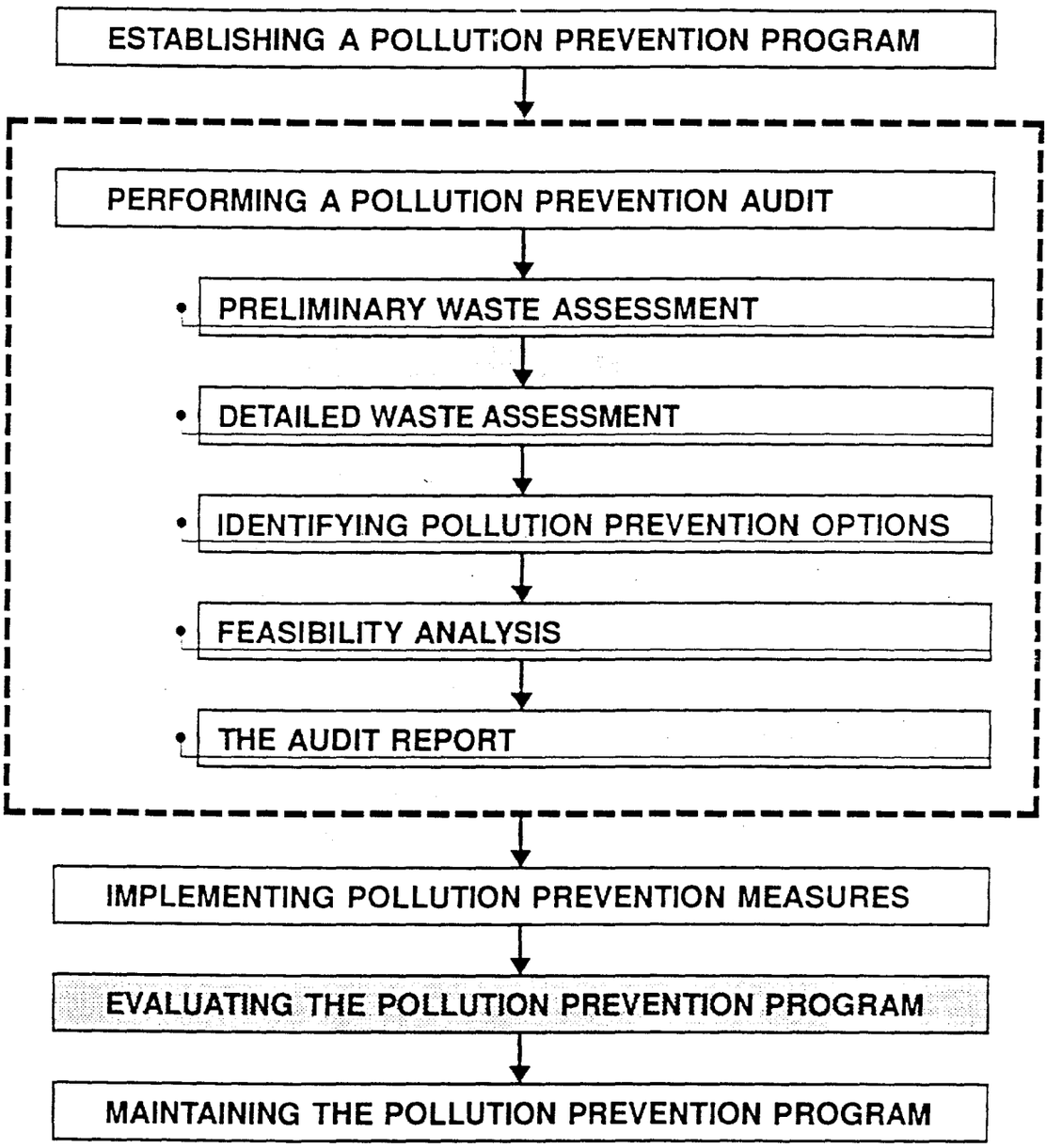
EVALUATING THE POLLUTION PREVENTION PROGRAM


ESTABLISHING A POLLUTION PREVENTION PROGRAM
PERFORMING A POLLUTION PREVENTION AUDIT
• PRELIMINARY WASTE ASSESSMENT
• DETAILED WASTE ASSESSMENT
• IDENTIFYING POLLUTION PREVENTION OPTIONS
• FEASIBILITY ANALYSIS
• THE AUDIT REPORT
IMPLEMENTING POLLUTION PREVENTION MEASURES
EVALUATING THE POLLUTION PREVENTION PROGRAM
MAINTAINING THE POLLUTION PREVENTION PROGRAM

EVALUATING THE POLLUTION PREVENTION PROGRAM

PURPOSE : Develop a pre-program baseline to be used for measuring Pollution Prevention progress.

- Quantitative criteria
- Descriptive criteria

QUANTITATIVE CRITERIA

QUANTITATIVE CRITERIA

- Disposal cost savings
- Reduced insurance claims
- Monitoring data
- Amount of waste generated
- Amount of waste recycled
- Levels of hazard (toxicity, acidity, reactivity, ignitability

QUANTITATIVE CRITERIA

QUANTITATIVE MEASUREMENT MODELS

- Actual change
- Production-normalized change
- Throughput ratio
- Degree of hazard

QUANTITATIVE CRITERIA

PROBLEMS WITH DEFINING AN ACCURATE BASELINE

- Data quality
- Adjusting for production
- Aggregating increases and decreases

QUANTITATIVE CRITERIA

PROBLEMS ASSOCIATED WITH COMPARING CURRENT DATA TO THE BASELINE

- Delayed effects of Pollution Prevention programs
- Real vs. paper changes
- Tendency to attribute any change to Pollution Prevention

DESCRIPTIVE CRITERIA

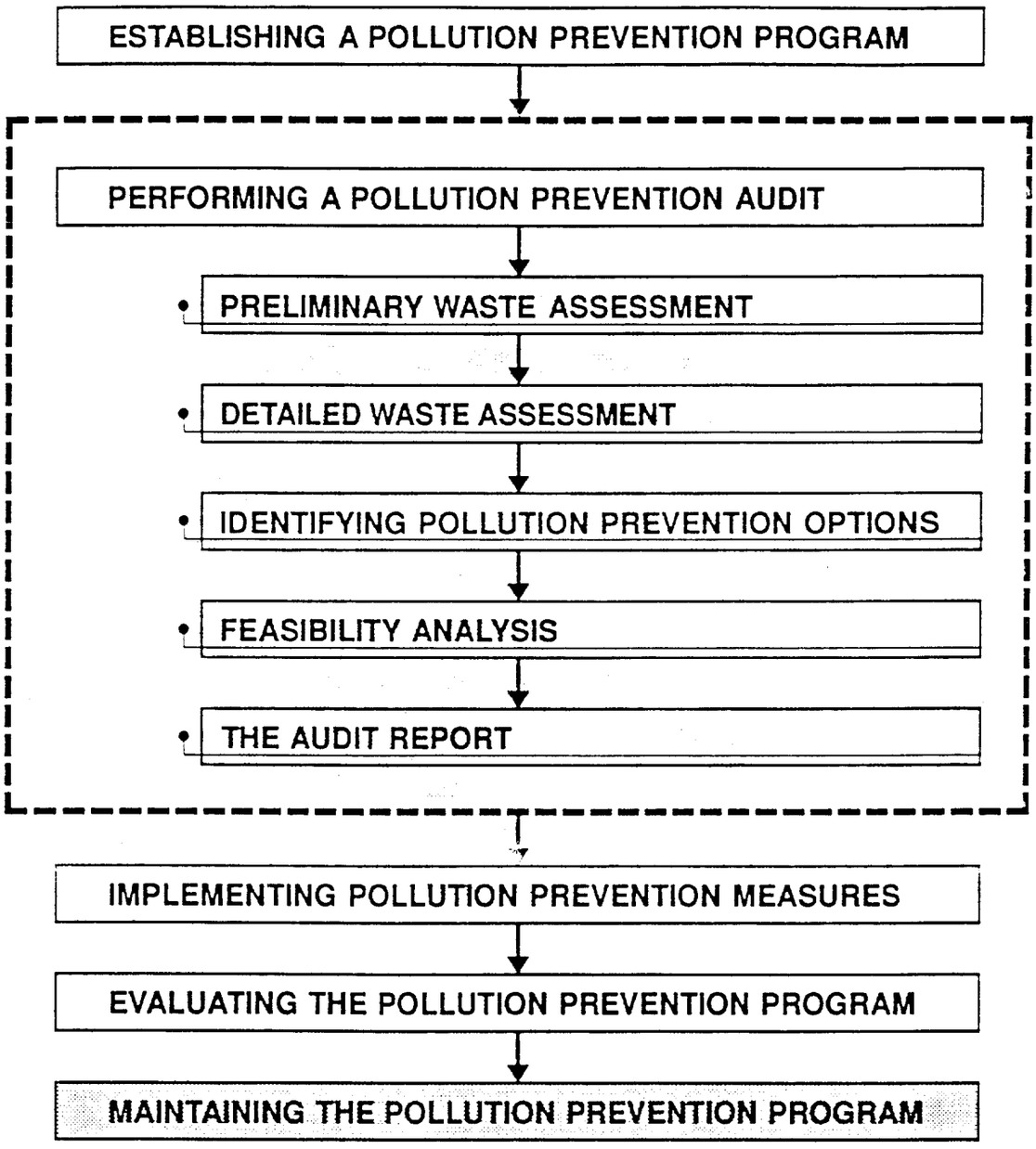
360

DESCRIPTIVE CRITERIA

- Number of Pollution Prevention projects
- Number of projects showings quantity reductions
- Number of auditors
- Number of completed audits
- Levels of training offered
- Levels of funds allocated to Pollution Prevention

6.

MAINTAINING THE POLLUTION PREVENTION PROGRAM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MAINTAINING THE POLLUTION PREVENTION PROGRAM

PURPOSE : Ensure that the Pollution Prevention Program is on-going and leads to continual improvements

- Have employees review processes and operations to determine where and how toxic substances are used and hazardous wastes are generated
- Solicit recommendations from employees on ways to continue elimination or reduction of wastes produced
- Find ways to involve suppliers and customers in the continual effort
- Acknowledge and reward employee contributions to the Pollution Prevention effort
- Develop ways of obtaining data for areas of gaps in original audit
- Relay results of measured progress to the personnel
- Set up internal waste charging system
- Set up financial reward system to provide incentives for proactive efforts
- Make waste auditing a regular event and train employees to perform the audits
- Develop files on new technologies and "cleaner" products
- Establish a Pollution Prevention Awareness program

7.

REFERENCE MATERIALS

PERFORMING A POLLUTION PREVENTION AUDIT

CASE STUDIES

CASE STUDY 2: LEATHER MANUFACTURE

Company B operates a tannery in south-east Asia processing cattle hides into finished leather, mainly for side upper leather in shoe manufacture. Treatment of the hides involves a series of batch operations involving application of a wide range of physical and chemical processes. Wastewaters discharged contain pollutants from the hides, products from their decomposition, and chemicals and various spent solutions used for hide preparation and during the tanning process. Solid wastes and some atmospheric emissions also arise.

The company was required to meet new government standards for discharge of wastewater to the local watercourse. This necessitated improvements to existing treatment facilities which were then limited to crude settlement in three lagoons operated in series. Primary sludge produced was disposed of in liquid form on a large area of surrounding land.

In the light of this situation, the company engaged a local consulting engineering firm to assist their staff in carrying out a waste audit and waste reduction programme with a view to developing the best and most cost-effective solution to the waste treatment and disposal problems.

The principal tannery operations carried out, typical of many tanneries throughout the world, may be summarised as follows.

Pretanning (or Beamhouse) Operations

- soaking of the imported, preserved (wet-salted) hide in water overnight to remove blood, dung, curing salt and water-soluble and saline-soluble proteins;
- unhairing (complete dissolving of all hair) by immersion in lime and sodium sulphide - and subsequent reliming;
- trimming and mechanical removal of extraneous tissue from the flesh side of the hides - and subsequent splitting (lime splitting) of the upper two-thirds grain layer from the lower, less valuable split layer;
- deliming by treatment with a weak acid (lactic acid) and bating with an enzyme-based chemical to remove hair remnants and degraded proteins;
- pickling using salt and sulphuric acid solutions to give the required acidity to the skins to prevent subsequent precipitation of chromium salts on the skin fibres - pickled splits are then sold to other tanneries for further processing, only the grain layers being tanned and finished by Company B.

Thus, wastewaters from the beamhouse contain high levels of suspended solids and dissolved organic matter, curing salt and grease, in addition to unused process chemicals (particularly sulphides); they will also be alkaline, having a high oxygen demand.

Tanning

Chrome tanning is carried out using chromic sulphate. The tanning process stabilises the proteineous (collagen) network of the hide. Acidic effluents are produced which contain unused trivalent chromium salts.

Post-Tanning Operations

These involve:

- pressing (samming) to remove moisture;
- a second levelling by shaving;
- dyeing and softening of the tanned hide with emulsified oils (fatliquoring), preceded by occasional secondary tanning using synthetic tannins (syntans) and tanning extracts;
- drying and final trimming;
- surface coating and buffing (finishing)

The following case study describes the waste audit/waste reduction approach taken.

PHASE 1: PREASSESSMENT

Step 1: Audit Focus and Preparation

It was decided that the study investigations would be carried out by a chemical engineer from the consulting firm's staff who had previous experience of carrying out waste audits, assisted by the tannery's plant chemist.

Company B's own laboratory was not equipped to carry out many of the tests normally associated with wastewater analysis and so arrangements had to be made to deliver samples to a local private company providing laboratory analytical services.

In view of government pressures, it was decided to concentrate on wastewater discharges arising from the beamhouse and subsequent tanning operations. However, atmospheric emissions were also investigated having particular regard to health and safety. Solid waste arisings, in particular wastewater treatment plant sludges, were also studied.

The waste audit team was keen to gain the support of production personnel in order to ensure that comprehensive information on all tannery operations could be readily obtained. As a first step therefore, the study objectives were fully explained to selected staff responsible for the various production activities.

The investigations were initiated by gathering relevant information from company files. This preliminary search yielded site and drainage plans, raw material purchase records and water meter records associated with on-site borehole abstraction.

A preliminary check on water usage was carried out by calculating the water usage per tonne of wet-salted hide processed. This was found to be 61 m^3/tonne. It was noted that this was some 22% higher than the typical average working figure of 50 m^3/tonne reported in technical literature, suggesting that ways of introducing considerable water savings should be possible as a result of the waste audit/waste reduction study.

Step 2: Listing Unit Operations

The consultant and the plant chemist started the tannery study by walking around the processing and waste treatment areas, listing all the unit processes and making notes on their function and use. Help was also sought from various plant operators who were familiar with the day to day plant operations. The unit operations were listed in Table 1, with processes which did not produce liquid waste shown in brackets.

Table 1: Unit Operations

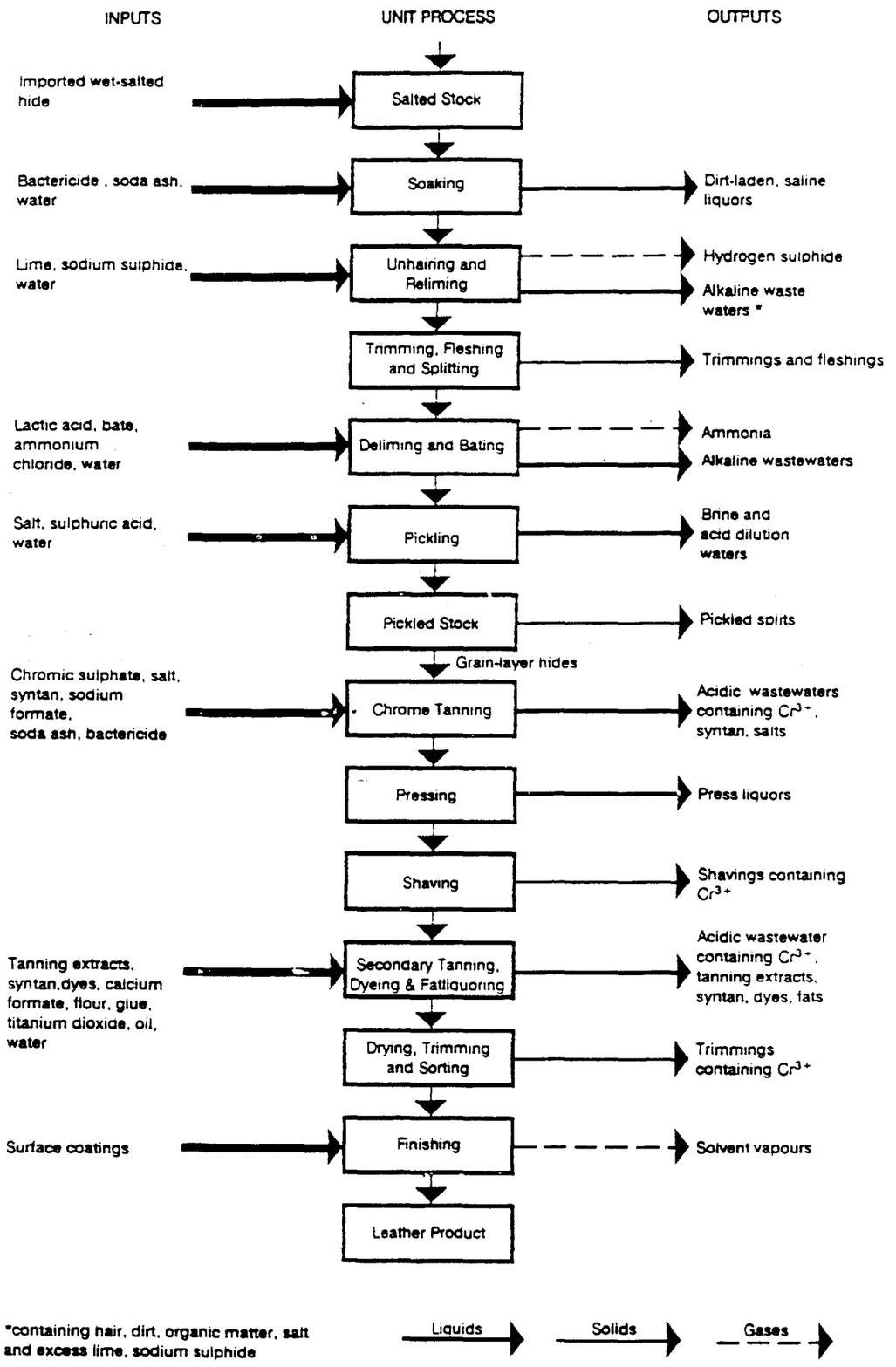
Soaking
Unhairing and Reliming
(Trimming, Fleshing and Splitting)
Deliming and Bating
Pickling
Chrome Tanning
Pressing
(Shaving)
Secondary Tanning, Dyeing and Fatliquoring
(Drying, Trimming and Sorting)
(Finishing)

As part of the company's long-term planning, the plant chemist noted that consideration was being given to moving the hide splitting operations further downstream the process line (after tanning) in order to improve the accuracy of splitting and hence overall process control, as commonly practised at other tanneries. The existing arrangement and design of process units, many of which were relatively old, did not however lend themselves to this change being implemented rapidly.

Step 3: Constructing Process Flow Diagrams

A flow diagram was then prepared to illustrate the interrelationship between the various unit operations (Figure 1).

Figure 1: Schematic Diagram of Tannery Operations



PHASE 2: MATERIAL BALANCE: PROCESS INPUTS AND OUTPUTS

Step 4: Determining Inputs

The audit preparation phase (Step 1) had already highlighted the availability of well-documented raw material purchasing records. The data produced also proved to be a good check on the raw material quantities quoted by the plant foremen per unit operation.

The raw material usage data obtained were set out as in Table 2.

Table 2: Annual Consumption of Process Chemicals

Process Chemicals	tonnes/annum
Sodium Chloride (other than curing salt present in raw hide)	622
Hydrated Lime	1,123
Sodium Sulphide (62% Na_2S)	445
Sulphuric Acid	160
Soda Ash (anhydrous sodium carbonate)	74
Bate (95% ammonium sulphate, 5% enzymes)	65
Calcium Formate	40
Lactic Acid (30%)	35
Sodium Formate	26
Bactericide	19
Ammonium Chloride	9
Sub-total	2,618
Chemicals Absorbed by the Hide (i)	
Tanolin (16% chromium)	760
Syntans A & B	424
Dyes	77
D-1 Oil	17
Other Oils	295
Tannin Extracts	190
Soyanch Flour	45
Titanium Dioxide	30
Methyl Cellulose	9
Semi-Sol Glue	17
Sub-total	1,864
Total	4,482

(i) Absorption estimated at 90%, 10% discharged to waste - except for Tanolin, absorption 75%, 25% discharge to waste

Due to the nature of the raw materials and the well-organised materials storage system which was found to be in operation, no significant handling losses were occurring.

It was noted that the company incurred no charges for consumption of water drawn from a site borehole. A separate town water (potable) supply was available for domestic use. Domestic wastewater passed to the nearby watercourse via a septic tank.

Having already tabulated the key production stages (Step 2), raw material usage listed in Table 2 was used to derive average quantities per unit operation throughout the tannery, on both a daily basis and per tonne of hide processed.

The data compiled were set out in Table 3.

Table 3: Chemical Inputs per Tannery Unit Operation

Unit Operation	kg/tonne hide (at unit operation)		kg/tonne wet-salted hide	kg/d
Soaking:				
Bactericide	1.6	(i)	1.6	64
Sodium Carbonate	0.8	(i)	0.8	32
Unhairing/Reliming:				
Hydrated Lime (unhairing)	48	(i)	48	1,920
Sodium Sulphide (62% Na_2S)	43	(i)	43	1,720
Hydrated Lime (reliming)	58	(i)	58	2,320
Deliming/Bating:				
Lactic Acid	5	(ii)	4.3	172
Bate	10	(ii)	8.7	348
Ammonium Chloride	1.3	(ii)	1.1	44
Pickling:				
Sodium Chloride	60	(ii)	51.9	2,076
Sulphuric Acid	21	(ii)	18.2	728
Chrome Tanning:				
Tanolin (basic chromic sulphate, 16% Cr^{3+})	60	(ii)	51.9	2,076
Sodium Chloride	60	(ii)	51.9	2,076
Syntan A	25	(ii)	21.6	864
Sodium Formate	8.9	(ii)	7.7	308
Sodium Carbonate	10	(ii)	8.7	348
Bactericide	1	(ii)	0.9	36
Syntan B	41	(ii)	35.5	1,420
Secondary Tanning, Dyeing and Fatliquoring:				
Dyes	20	(iii)	7.0	280
Calcium Formate	10.3		3.6	145
Syntan B	44	(iii)	15.4	616
Soyarich Flour	16	(iii)	5.6	224
Titanium Dioxide	8	(iii)	2.8	112
Glue/Methyl Cellulose	8	(iii)	2.8	112
Tannin Extracts & Oils	118	(iii)	41.3	1,652
Total				19,693

(i) Based on 40 tonnes wet-salted hide per day
(ii) Based on fleshed, split/trimmed hide, after reliming - 34.6 tonnes per day
(iii) Based on chrome tanned leather, after pressing/shaving - 14.0 tonnes per day

Step 5: Recording Water Usage

The next step was to record the water usage at the tannery and determine how it was used. It was noted that water obtained by the company from the site borehole was pumped to a covered storage tank at ground level and then pumped again to a high-level storage tank. Water then gravitated to the site distribution mains under static head via a water meter, readings for which were recorded weekly in a log book.

Analysis of these records indicated a daily average total water consumption for the site of 2.450 m^3/d. This figure was then broken down into average water usage per tannery unit operation in a similar manner to that carried out for the process chemicals. Since the tannery wet processes were all carried out in revolving vessels of known capacity, providing mechanical agitation to accelerate the wet-chemical operations, batch process water inputs were readily quantifiable. Rinsewater usage which was continuous for a fixed duration per batch was also known from previous work carried out by the company. This had involved checking the time taken to fill a vessel of known volume for a given water valve setting.

The results were summarised as set out in Table 4.

Table 4: Water Inputs per Tannery Operation

Unit Operation	m^3/tonne hide (at unit operation)		m^3/tonne wet-salted hide	m^3/d
Soaking:				
Prewash	4.3	(i)	4.3	172.0
Process Water	1.9	(i)	1.9	76.0
Rinse Water	2.1	(i)	2.1	84.0
Unhairing/Reliming:				
Process Water	1.9	(i)	1.9	76.0
Rinse Water	11.0	(i)	11.0	440.0
Soak Water (reliming)	1.9	(i)	1.9	76.0
Rinse Water	2.1	(i)	2.1	84.0
Deliming/Bating:				
Pre-rinse	4.2	(ii)	3.635	145.4
Process Water	1.0	(ii)	0.865	34.6
Rinse Water	1.385	(ii)	1.2	48.0
Pickling:				
Brine Water	2.49	(ii)	0.215	8.6
Acid Dilution Water	0.84	(ii)	0.073	2.9
Chrome Tanning:				
Process Water	0.586	(ii)	0.507	20.3
Rinsing	4.51	(ii)	3.9	156.0
Pressing:	0.202	(ii)	0.175	7.0
Secondary Tanning, Dyeing and Fatliquoring:				
Prerinse	9.15	(iii)	3.2	128.0
Process Water	0.4	(iii)	0.14	5.6
Rinse Water	18.6	(iii)	6.5	260.0
Process Water	0.4	(iii)	0.14	5.6
General Floor and Plant Washwater			15.5	620.0
Total - Process Waters	-		12.115	484.6
- Rinse Waters	-		33.635	1,345.4
- General Washdown	-		15.500	620.0
- Total	-		61.250	2,450.0

(i) Based on 40 tonnes wet-salted hide per day
(ii) Based on fleshed, split/trimmed hide, after reliming - 34.6 tonnes per day
(iii) Based on chrome tanned leather, after pressing/shaving - 14.0 tonnes per day

Step 6: Measuring Current Levels of Waste Reuse/Recycling

It was noted that no wastes were reused/recycled at the tannery.

Step 7: Quantifying Process Outputs

The audit team listed the process outputs from each tannery unit operation as set out in Table 5 below.

Table 5: Process Outputs

Unit Operation	Wastewater	By-Product/ Waste Reuse	Atmospheric Emissions
Soaking	Process and Wash/Rinse Waters	-	-
Unhairing/Reliming	Process and Rinse Waters	-	Hydrogen Sulphide
Trimming, Fleshing and Splitting	-	Trimmings and Fleshings	-
Deliming/Bating	Process and Rinse Waters	-	Ammonia
Pickling	Process Brine/ Acid Dilution Waters	-	-
Pickled Hide Storage	-	Pickled Splits	-
Chrome Tanning	Process and Rinse Waters	-	-
Pressing and Shaving	Press Liquors	Shavings	-
Secondary Tanning, Dyeing and Fatliquoring	Process and Rinse Waters	-	-
Drying, Trimming and Sorting	-	Trimmings	-
Finishing	-	-	Solvent Vapours
Final Product	-	Finished Leather (grain layer)	-

Action was then taken to quantify these outputs in Steps 8, 9 and 10.

Step 8: Accounting for Wastewater

Process wastewater flows were based on totalling up batch water inputs and making allowances where appropriate for water retention by the hide at each process stage based on percentages reported in technical literature.

Composite samples of the various discharges were also taken for laboratory analysis.

The results of this exercise were summarised in Table 6.

Table 6: Average Flows, Strengths and Pollution Loads of Strong Liquors

Unit Operation	Flow			BOD			SS		
	m^3/d	% of total	pH	mg/l	kg/d	% of total	mg/l	kg/d	% of total
Soaking	276	42.1	6.8	2.200	607	19.8	4.400	1.215	30.0
Unhairing	103	15.7	11.5	15.500	1.597	52.0	22.100	2.276	56.1
Reliming	103	15.7	11.7	650	67	2.2	1.650	170	4.2
Delime and Bating	66	10.1	9.5	6.000	396	12.9	2.100	139	3.4
Pickling	37	5.6	2.7	2.900	108	3.5	5.200	192	4.7
Chrome Tan & Press Liquors	33	5.0	3.6	6.500	215	7.0	1.100	36	0.9
Secondary Tanning, Dyeing & Fatliquoring									
- 1st dump	19	2.9	4.0	2.000	38	1.2	600	11	0.3
- 2nd dump	19	2.9	3.7	2.200	42	1.4	850	16	0.4
Total	656	100.0	-	-	3.070	100.0	-	4.055	100.0

It was decided that having quantified the main, strong-liquor pollution loads per unit operation, separate quantification of running rinsewater pollution loads per unit operation was not justified since this would have meant setting up numerous V-notch weirs and many additional sampling points, thus increasing significantly the time input and analytical work required.

The relatively weak continuous-flow rinse waters were thus monitored using a V-notch weir located in a common drain within the tannery and combining frequent spot samples to give a daily composite for the whole tannery. Total rinsewater flow including general floor and plant washdown was estimated to be 1,944 m^3/d with an associated BOD and SS strength of 273 mg/l and 396 mg/l SS. Corresponding pollution loads (flow x strength) were thus 530 kg BOD/d and 770 kg SS/d.

The overall wastewater flows and BOD and SS strengths and pollution loads were then tabulated in Table 7.

Table 7: Combined Wastewater Flows, Strengths and Pollution Loads

Wastewater	Flow	BOD		SS	
	m^3/d	mg/l	kg/d	mg/l	kg/d
Strong Liquors	656	4.680 (i)	3.070	6180 (i)	4.055
Rinse Waters/General Washdown	1.944	273	530	396	770
Total	2.600	1.430 (i)	3.600	1.950 (i)	4.825

(i) Concentrations calculated from flow/pollution load data

Based on an average 40 tonnes of wet-salted hide processed, it was noted that these overall figures equate to 65 m^3 wastewater/tonne, 90 kg BOD/tonne and 121 kg SS/tonne, ie fairly typical unit loads compared with average figures for similar tanneries elsewhere but some 20-25% high in terms of wastewater flow.

An assessment was also made of chromium and sulphide pollution loads based on selected additional wastewater analyses carried out. This yielded pollution loads of 198 kg Cr/d and 412 kg $S^{=}$/d, equivalent to 4.9 kg Cr/tonne and 10.3 kg $S^{=}$/tonne. Again, it was noted that these loads were fairly typical in the consultant's experience even for well operated tanneries, although somewhat higher (14% and 21% respectively) with respect to figures reported by WHO, 1982.

A number of other checks were also made. It was noted that while it was difficult to measure combined wastewater flows entering the wastewater treatment system, the final lagoon effluent discharged via a rectangular weir. In order to obtain some cross-check on the combined raw wastewater flow set out in Table 7, the final effluent flow to the nearby watercourse was monitored using this weir. An average flow over the study period of 2,200 m^3/d was recorded.

A limited number of samples of the lagoon effluent were taken and results compared with the raw wastewater analyses tabulated in Table 7. These indicated pollution load reductions averaging 40% BOD and 70% SS. Based on an average sludge concentration of 6% dry solids, calculations indicated that the volume of primary sludge generated averaged 56 m^3/d. The audit team noted that while this sludge was periodically being disposed of on surrounding land, this practice would not be allowed to continue in the future as liquid run-off caused additional pollution problems in the nearby watercourse, particularly during wet weather.

Step 9: Accounting for Gaseous Emissions

It was decided that consideration of atmospheric pollution issues in the context of this project did not justify the need for making use of portable gas detection equipment, such facilities in any case not being readily available. It was also considered that resources required to quantify gaseous emissions would be out of proportion to the extent of the problems occurring. However, various useful observations were made during the site survey.

A strong smell of hydrogen sulphide (H_2S) gas was evident at the primary sedimentation stage of the wastewater treatment plant. H_2S was also evident, although only to a limited extent, within the tannery processing areas where alkaline beamhouse liquors combined with subsequent acidic streams within the internal drainage system.

The plant chemist knew that the hydrogen sulphide was a highly-toxic gas having a threshold limit value (TLV) of 15 mg/m^3 (100 ppm by volume) in air. He also knew that the extent to which H_2S could be released from solution to atmosphere was pH dependent, high pHs favouring the ionised form (HS^-) and hence reduced risk of sulphide stripping. He therefore noted that any

future wastewater treatment scheme would be best designed to allow pretreatment of alkaline beamhouse liquors (pH at least 10) before they were allowed to mix with other, acidic waste flows.

No release of ammonia associated with deliming/bating was apparent but it was noted that release of some solvent vapours in the working areas associated with leather finishing could be a potential health risk to production staff. Discussions with the management subsequently revealed that plans were already underway to install forced-ventilation equipment to cater for this problem.

Step 10: Accounting for Off-Site Wastes

The only wastes which were recycled were fleshings which were transported to a local rendering company; these amounted to an average of 9,200 kg/d.

Trimmings and shavings were disposed of to a local municipal landfill site and amounted to 14,600 kg/d.

No sale costs associated with disposal of the fleshings could be readily identified at the time of the waste audit. It was later established that no charge was levied by the tannery in return for the rendering company providing transportation facilities at their cost.

Trimmings and shavings were disposed of at an annual cost of US$14,000.

Step 11: Assembling Input and Output Information for Unit Operations

From the information collected the preliminary material balances were started by assembling the input and output data for the tannery and the wastewater treatment plant. These were tabulated under Step 12.

Step 12: Deriving a Preliminary Material Balance for Unit Operations

A preliminary material balance of data associated with operations within the tannery was first drawn up on an overall input/output materials basis. The information was tabulated as set out below.

Inputs	kg/d
Raw Hide	40,000
Chemicals (other than curing salt present in raw hides)	19,693
Water	2,450,000
Total	2,509,693

↓

Overall Tannery Operations

↓

Outputs	kg/d
Trimmings and Shavings	14,600
Fleshings	9,200
Pickled Split Layer	13,500
Finished Leather	5,600
Wastewater	2,600,000
Gaseous Emissions	Not quantified but not considered to be a major output
Total	2,642,900

A material balance was then drawn up on a unit operation basis with specific reference to chromium and sulphide. A material balance for the wastewater treatment plant was also compiled.

Inputs	kg/d S*	
Unhairing	430	(a)

(a) Based on 1,720 kg/d sodium sulphide containing 25% S*

↓

Unhairing

↓

Outputs	kg/d S*	
Unhairing, Reliming, Delime and Bating	412	(a)
Rinsewaters	5	(b)
Total	417	

(a) Based on 103 m^3/d unhairing liquors at 4,000 mg/l S*
(b) Based on 1,944 m^3/d rinsewaters containing 2.5 mg/l S*

Inputs	kg/d Cr	
Chrome Tanning	332	(a)

(a) Based on 2.076 kg/d Tanolin containing 16% Cr^{3+}

Chrome Tanning

Outputs	kg/d Cr	
Chrome Tan & Press Liquors	83	(a)
Chrome Leather	249	(b)
Rinsewaters	3	(c)
Total	335	

(a) Based on 33 m^3/d chrome liquors at 2.500 mg/l Cr^{3+}
(b) Based on 2.076 kg/d Tanolin containing 16% Cr^{3+} and 75% chrome absorption into hide
(c) Based on 1.944 m^3/d rinsewaters containing 1.5 mg/l Cr^{3+}

Inputs	m^3/d
Raw Wastewater	2.600

Wastewater Treatment Plant

Outputs	m^3/d
Primary Effluent	2.200
Primary Sludge	56
Total	2.256

Step 13: Evaluating the Material Balance

The waste audit team were confident that they had obtained an adequate material balance (within 5-10%) for the tannery as a whole as well as for the specific chromium and sulphide chemicals used.

The material balance for the wastewater treatment plant was also considered reasonable taking into account that some water seepage was possibly occurring through the base of the crude lagoons, thus contributing to the 13% difference between inflow and total outflows recorded.

Step 14: Refining the Material Balance

It was considered that the material balance information obtained was sufficient to meet immediate requirements but that it would be useful to carry out a further waste audit once any waste reduction measures had been implemented.

PHASE 3: SYNTHESIS

Step 15: Examining Obvious Waste Reduction Measures

It was noted that the rinsewater usage following unhairing was appreciable, amounting to some 18% of the total water usage throughout the tannery.

It was considered that significant savings could be achieved at this stage by changing from a 4-hour running rinse to a two-stage batch wash operation, each of 20-25 minutes duration. It was anticipated following a short-term trial that it should be possible to achieve a consistent 60% reduction in rinsewater usage, that is, from 440 m^3/d to 176 m^3/d.

The audit team also realised that considerable water wastage was taking place by tannery staff leaving numerous hoses running in between general floor and equipment washdown operations. On the basis of an average of 15 hoses in continuous use, it was estimated that water passing to drain surplus to actual requirements could be as much as 136 m^3/d, some 5% of the total waste-water flow. Recommendations were therefore made for the fitting of pistol-grip self-closing valves on all hoses in use throughout the tannery.

Thus, it was concluded that total wastewater flows could be reduced from 2,600 m^3/d to 2,200 m^3/d, reducing the wastewater production to a more respectable 55 m^3/tonne wet-salted hide processed.

Step 16: Targetting and Characterizing Problem Wastes

a) Sulphide Liquors

As indicated in Step 9, it was evident that pretreatment of all sulphide-containing liquors was needed before they became mixed with other acidic flows; the possibility also existed of at least partial recycle of fine-screened sulphide liquors in subsequent unhairing operations.

The management favoured a flexible approach with the treatment system designed to handle the total daily sulphide liquor flow if required, conscious that sulphide liquor recycle would probably require a higher level of surveillance of the efficiency of the unhairing operation which might not be readily achieved on a consistent basis in practice.

The audit team then proceeded to draw up design flow and strength data for the pretreatment of sulphide-bearing waste streams; and also for the subsequent combined wastewater treatment facility required to meet the government's new discharge requirements.

Sulphide-bearing liquors were taken as being all the process and rinsewaters associated with the unhairing process and all wastewater associated with deliming/bating other than the final rinse. The resultant average design flow and sulphide load assessed were as shown in Table 8.

Table 8: Characteristics of Sulphide-Bearing Wastewaters

Parameter	Actual		Design	
Flow	590 m^3/d	*	600 m^3/d	
Sulphide	412 kg/d	(700 mg/l)	420 kg/d	(700 mg/l - ave.)
			600 kg/d	(1,000 mg/l - max.)

* assuming unhairing-stage rinsing carried out on a 2-stage batch basis to reduce water usage (equivalent to 27% of total wastewater flows following instigation of water saving)

An assessment was made of the likely BOD reduction due to oxidation of sulphide. The theoretical oxygen uptake rate due to oxidation of sulphide was taken as 0.75-2.0 kg O_2/kg $S^{=}$ depending on the ratio of the thiosulphate:sulphate oxidation products. Taking an average 1.4 kg O_2/kg $S^{=}$ and a 97% $S^{=}$ reduction (down to 20 mg/l $S^{=}$), this gave a BOD reduction of 560 kg/d.

With reference to Table 7, the combined wastewater BOD load can be expected to reduce from 3,600 kg/d to 3,040 kg/d, equivalent to 1,380 mg/l BOD in a reduced flow of 2,200 m^3/d. Regarding the effect on suspended solids loads as a result of fine-screening of sulphide liquors, actual removals were difficult to predict accurately without further test work. As a conservative approach therefore, it was decided that the calculated total SS load of 4,825 kg/d (Table 7) should be carried forward as a design SS load for sizing and budgetary costing of the combined wastewater treatment plant; this gave a concentration of 2,190 mg/l SS at the predicted future reduced flow.

b) *Chrome Liquors*

The audit team considered the possibility of recovering chrome from the chrome-bearing liquors by fine screening, addition of sodium carbonate to precipitate chrome hydroxide (at pH 8-8.5), filter-plate pressing of the resultant sludge and then conversion of the chrome precipitate to soluble chromic sulphate using sulphuric acid.

Discussions with the management revealed that this possibility had been considered in the past but was not favoured on overall technical and cost grounds unless the benefits of economy of scale could be introduced by providing a centralised chrome recovery plant to serve all tanneries in the local area. While some preliminary discussions had been held through the national tannery association, such a scheme was not foreseen at this stage.

It was agreed therefore that for the present, the design of a new wastewater treatment plant should assume that chrome would be precipitated and disposed of off-site as part of the primary sludge generated.

Step 17: Segregation

In order to segregate sulphide liquors for separate pretreatment, it was decided to divert existing drainage outlets in the unhairing area to a batch treatment plant located within the existing tannery process building.

Treated flows would then be combined with all other wastewaters at a new treatment plant located close to the existing settlement lagoon facility.

Step 18: Developing Long-Term Waste Reduction Options

The waste audit consultant was responsible for drawing up outline proposals for the required new wastewater treatment facilities.

Consideration was given to available methods of sulphide treatment. These included:

- acidification to pH 2-3 and aeration, with absorption of the resultant hydrogen sulphide gas in caustic soda solution within packed-tower scrubbers prior to discharge of the resultant liquor to drain or reuse;
- precipitation with ferrous or ferric salts;
- oxidation using chlorine or hydrogen peroxide;
- oxidation using aeration with a manganese catalyst.

The latter method was considered the most technically satisfactory and cost-effective solution following fine screening. This view was supported by reference to available information sources concerning operational experience elsewhere.

It was decided to divert existing drainage outlets in the unhairing area to a mechanical self-cleaning screen (1 mm) located in a modified floor channel, the upper end being designed to convey screenings to an adjacent skip.

Screened flows would then gravitate to a submersible pumping station to lift flows into one of two batch-treatment oxidation tanks, one to be used for treatment and the other to be available for receiving the next batch of liquor. A diffused-air system, using non-clog coarse-bubble diffusers, was selected to provide mixing and aeration in each tank and a facility for dosing a solution of manganese sulphate catalyst was incorporated.

The main treatment plant for pretreated sulphide liquors combined with all other wastewater flows involved the following features:

- flow/pollution load balancing incorporating coarse-bubble aeration/mixing;
- pH correction (if required), chemical flocculation with alum and polyelectrolyte and subsequent primary settlement:
- extended aeration treatment using low-speed mechanical surface aerators (sized to provide a robust biological system capable of withstanding fluctuating loads);
- batch storage/thickening of mixed primary and surplus secondary sludges prior to pumping to drying beds and subsequent disposal of sludge cake to landfill.

Provision for iron salt dosing to the sludge storage/thickening tank was incorporated to precipitate any sulphide formed as a result of anaerobic activity within the tank and hence to minimise odour problems occurring.

A schematic diagram of the proposed treatment plant was compiled as illustrated in Figure 2.

Step 19: Environmental and Economic Evaluation of Waste Reduction Options

Company B was placed in a position of having to upgrade its wastewater treatment system in order to comply with new discharge standards imposed by the government, part of a new emphasis on the need to control pollution of the environment.

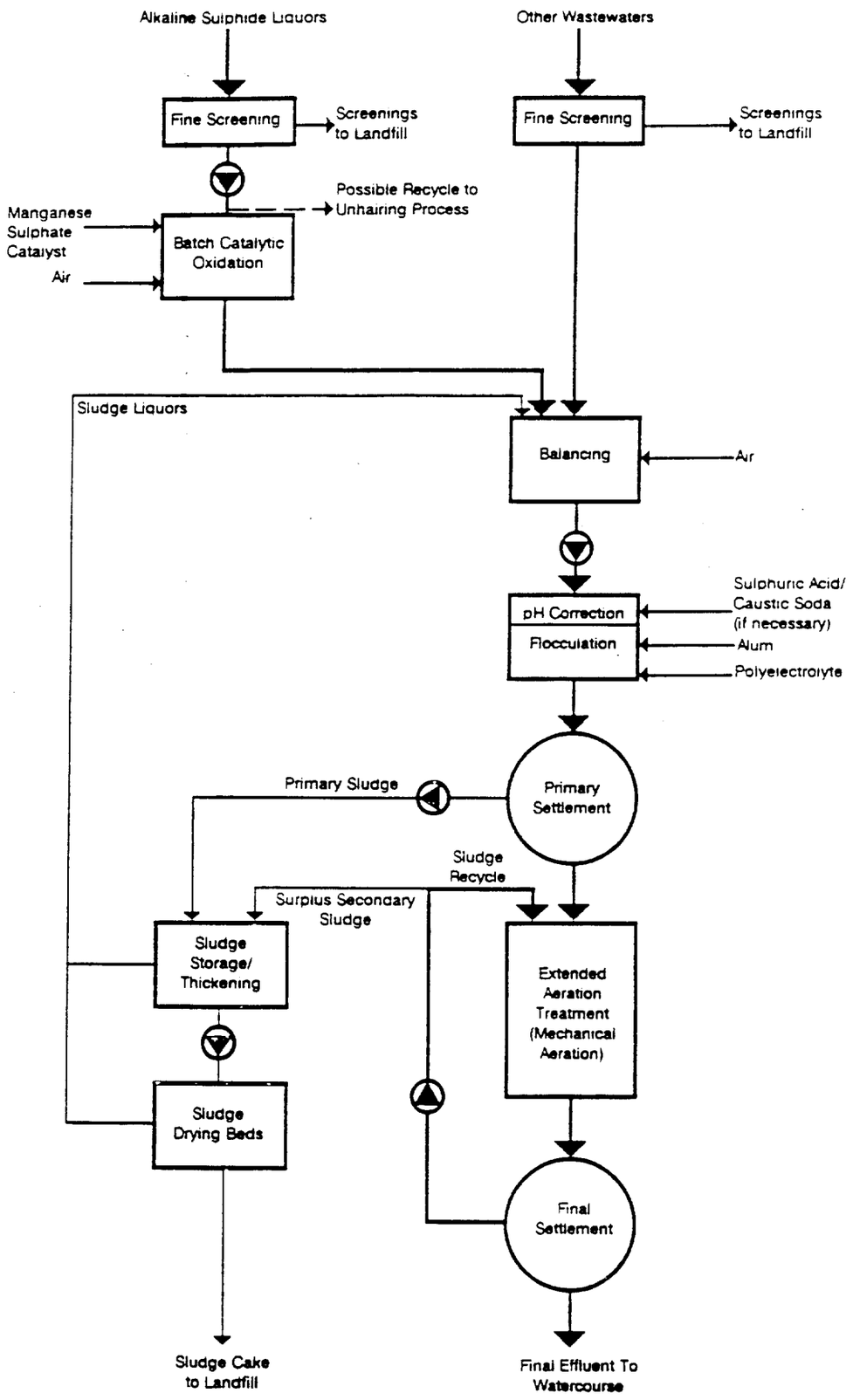
The new effluent discharge standards laid down were 40 mg/l BOD and 60 mg/l SS. Hence, provision of a new treatment facility designed to meet these standards consistently was expected to improve the quality of the local watercourse substantially.

There was a clear need to minimise capital and operating costs of the treatment scheme to ensure the overall financial viability of the company's operations. Therefore, in preparing outline designs for budgetary purposes, particular attention was paid to providing a plant which would be robust and relatively simple to operate.

The cost of the treatment scheme drawn up was estimated at US$500.000 including contingencies and design/construction supervision fees. This reflected a conservative approach to the sizing of the activated sludge process, particularly in terms of aeration capacity. It also took into account the availability of two redundant water storage vessels suitable for use as sulphide-liquor treatment tanks.

This approach was adopted to provide some flexibility over the mode of operation of the plant with a view to minimising operating costs - it would allow the primary settlement stage to operate without addition of chemical flocculants if desired, with consequent higher strength effluent

Figure 2: Schematic Diagram of Proposed Wastewater Treatment Plant



passing forward to the biological stage; overall sludge yields requiring ultimate disposal off-site would also be minimised. Provision for chemical flocculants at the primary stage was included however since it was felt that their use could enable the required final effluent quality to be achieved more consistently.

Step 20: Developing and Implementing an Action Plan: Reducing Wastes and Increasing Production Efficiency

The consultants engaged to carry out the waste audit/waste reduction studies presented the results of their findings to Company B's management. The data presented were used as a basis for submitting a planning application to the local government office for approval to design and install the proposed wastewater treatment plant.

During a subsequent meeting with the government concerning timing of the proposed design and construction work, Company B was informed that the introduction of a charging system for borehole abstraction was under consideration for possible implementation the following year. This development emphasised to the tannery management the importance of having carried out the waste audit/waste reduction investigations and the need to be alive to further water-saving possibilities in the future.

The waste audit/waste reduction investigations achieved the following objectives.

- A thorough appreciation of all the sources of waste at the tannery.
- Identification and quantification of the major sources of wastewater including waste sulphide and chromium contributions.
- Evaluation of processing efficiencies from assembled information on unit operations, raw materials, water usage, products and waste generation.
- Reduction of water usage and associated wastewater disposal problems.
- Identification of problem wastes (ie sulphide liquors) requiring special attention.
- Development of a waste management system which would comply with discharge regulations and result in a much-improved local environment.

CASE STUDY 3: PRINTED CIRCUIT BOARD MANUFACTURE

Company C manufactures double-sided and multi-layered circuit boards for the telecommunications and computer markets. The manufacturing of printed circuit boards involves a complex series of physical and chemical processing stages and as a result the wastewaters which are generated are complex, of variable composition and difficult to treat. To compound the treatment problems, many of the processing solutions contain proprietary chemicals whose composition is not readily available.

The main pollutants in printed circuit board manufacturing wastewaters are heavy metals, particularly copper. Company C's wastewater frequently exceeded the local authority's standards for discharges to the public sewerage system. Although the company had implemented some improvements to its wastewater treatment system in recent years, discharges in excess of the 5 mg/l limit on copper continued to occur and the local authority eventually decided to take legal action.

In response to these problems the company decided to conduct a waste audit in order to:

- bring to the attention of production personnel the importance of minimising wastage at source with a view to improving overall production efficiency while at the same time reducing both raw material costs and waste treatment costs;
- identify the sources of contamination;
- develop a waste reduction strategy to minimise contaminants at source;
- develop a sound understanding of the wastewater problems to facilitate the design of a cost-effective wastewater treatment system to comply with discharge standards.

The printed circuit board material is composed of a glass-fibre sheet with copper laminated on both sides. The uncut boards are received from the suppliers in large sheets and pass through a shearing stage to cut them to the desired size. The boards are then drilled and pass through a surface conditioning stage (deburring) before undergoing a series of treatments in the sensitising area (electroless plating). This treatment essentially coats copper into the holes and prepares the holes for electroplating.

The next stage involves the application of a photopolymer-resist material which masks off areas which do not need to be electroplated. The printed circuit areas are subsequently developed (to remove unexposed resist areas which are to be plated) and pass through microetching, copper electroplating, solder electroplating, resist stripping, copper etching and a number of other selected finishing treatments as specified by the customer. The last stages of manufacture involve final fabrication and electrical testing.

It can thus be seen that the printed circuit board manufacturing plant is complex and a great number of different process wastes are generated. The following case study describes the approach taken to overcome the long-standing waste treatment problems encountered by the company. The investigations were based on the step-by-step approach described in this waste audit manual and the studies highlighted a number of areas where processing and treatment efficiencies could be improved.

PHASE 1: PREASSESSMENT

Step 1: Audit Focus and Preparation

The waste audit programme was initiated by selecting an investigating team to carry out the required work and compiling all existing documentation and information relevent to the project.

In view of the scale of the investigatory work required, the audit team included representatives from each key manufacturing section. This not only increased employee awareness of and support for the study programme but enabled a full understanding of the factory processes and particular problem areas to be developed.

The audit team studied the practical aspects of initiating the required studies. It was decided that wastewater flow measurements and sampling could be readily conducted using internal resources but that it would be necessary to engage a contract laboratory to carry out the numerous wastewater analyses required.

Step 2: Listing Unit Operations

Due to the complex nature of the printed circuit board plant it was not considered appropriate to list all the unit operations in fine detail. Instead, following a detailed walk around the factory, the various manufacturing stages were compiled in terms of processing areas. Furthermore, as copper was by far the major contaminant of interest, it was decided at this stage to conduct the waste audit with specific reference to copper.

Figure 1 shows the general schematic process flow diagram which was constructed from the initial plant investigations. The areas where waste copper was generated were found to be the:

- deburring operation (sensitising);
- sensitising line (electroless plating);
- electroplating line (copper electroplating, solder electroplating, moist strip and copper etch);
- oxide coating area (including oxide deburring, oxide coating, solder stripping and lacquer finishing).

Step 3: Constructing Process Flow Diagrams

Once the main processing areas which generated waste copper had been identified the process flow diagrams were constructed for each area. This involved a more detailed study of each processing area and the identification of process inputs and outputs. In addition to the four processing areas mentioned, a process flow diagram of the existing wastewater treatment plant was also developed. Figures 2 - 6 show the process flow diagrams for these main processing areas. It should be noted that some diagrams are simplified for the purposes of the case study.

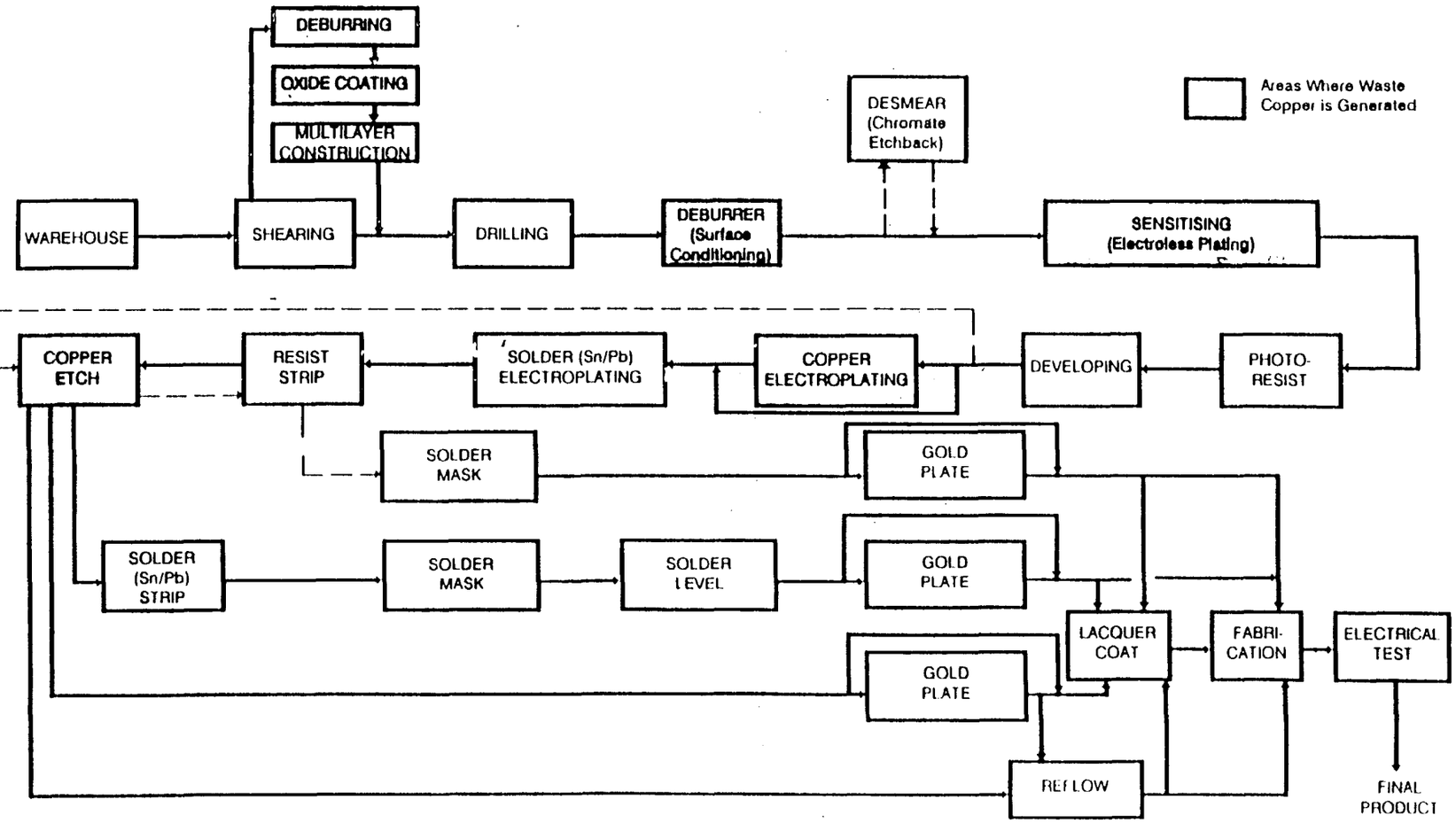


Figure 1: General Flow Diagram for the Printed Circuit Board Manufacturing Plant

Figure 2: Process Flow Diagram for Sensitising Deburrer

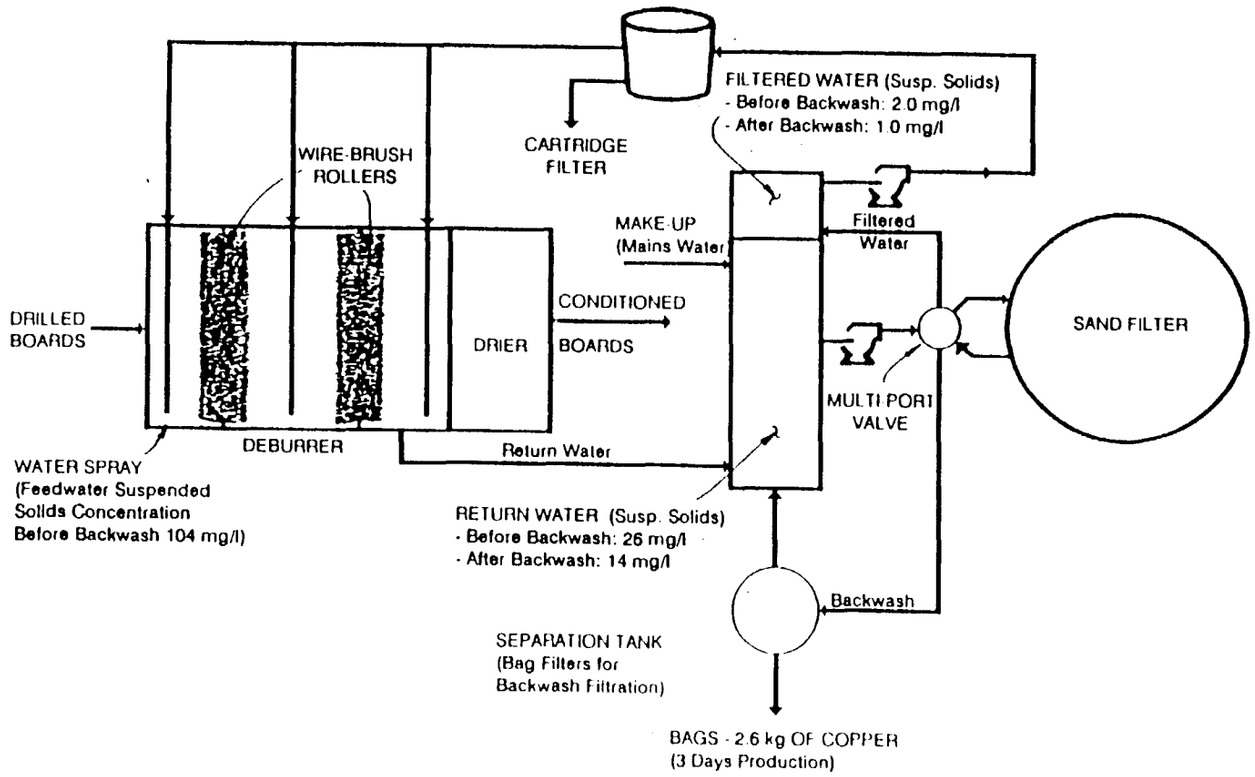
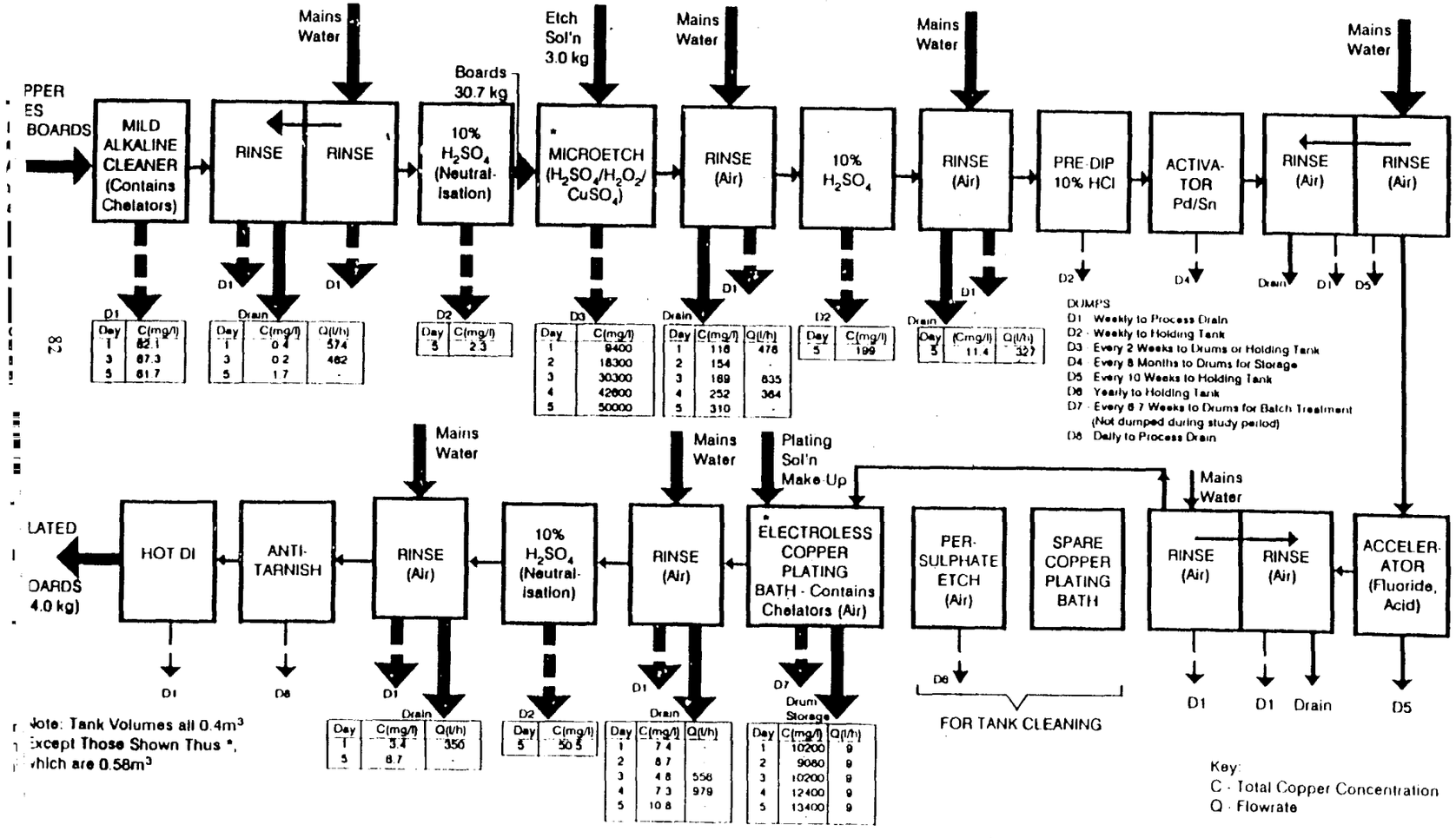


Figure 3: Process Flow Diagram for Sensitising (Electroless Plating) Area



Day	C(mg/l)
1	82.1
3	87.3
5	81.7

Day	C(mg/l)	Q(l/h)
1	0.4	574
3	0.2	462
5	1.7	-

Day	C(mg/l)
5	2.3

Day	C(mg/l)
1	9400
2	18300
3	30300
4	42600
5	50000

Day	C(mg/l)	Q(l/h)
1	116	478
2	154	-
3	169	835
4	252	364
5	310	-

Day	C(mg/l)
5	199

Day	(Cmg/l)	Q(l/h)
5	11.4	327

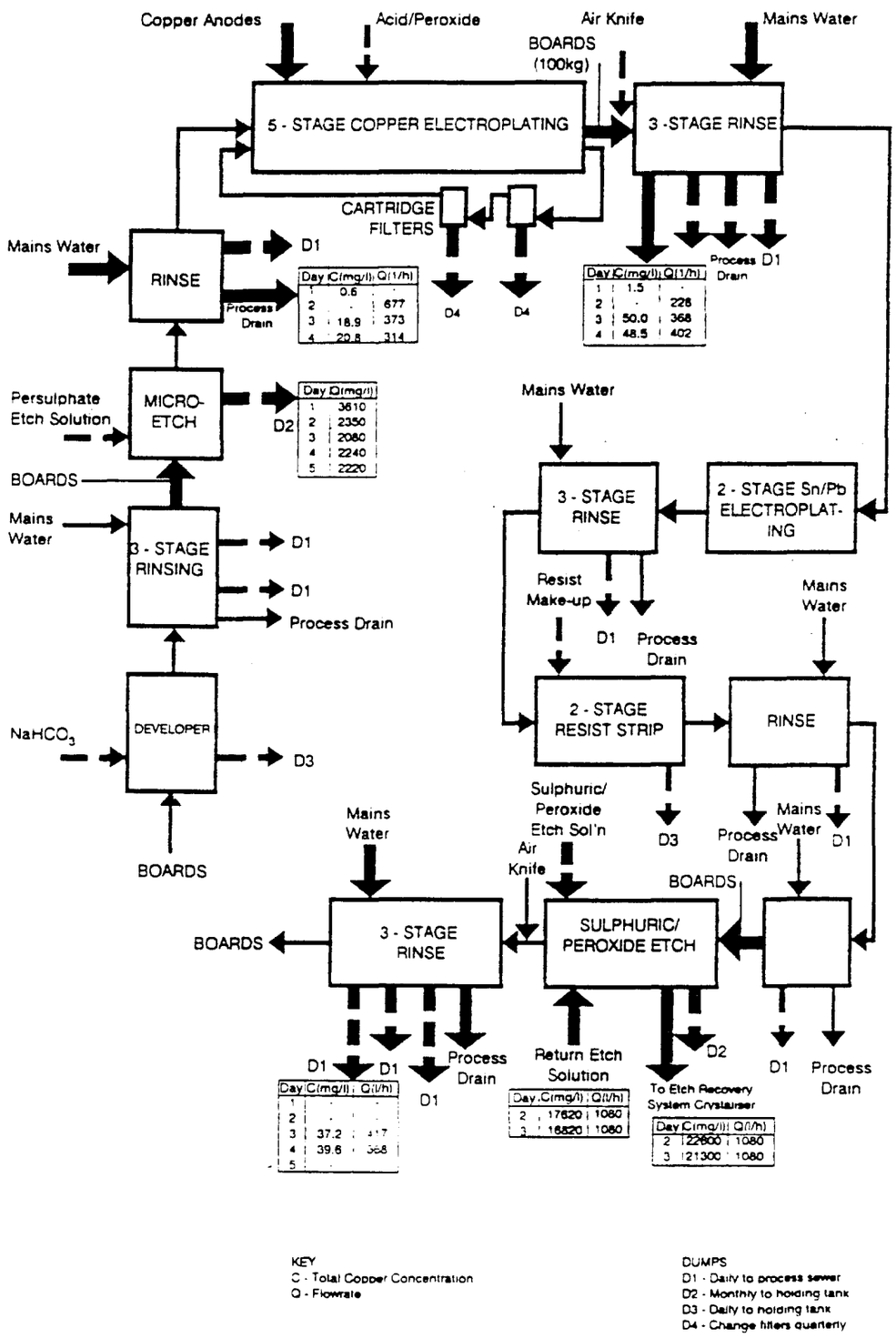
Day	C(mg/l)	Q(l/h)
1	3.4	356
5	8.7	-

Day	C(mg/l)
5	50.5

Day	C(mg/l)	Q(l/h)
1	7.4	-
2	8.7	-
3	4.8	558
4	7.3	979
5	10.8	-

Day	C(mg/l)	Q(l/h)
1	10200	9
2	9080	9
3	10200	9
4	12400	9
5	13400	9

Figure 4: Process Flow Diagram for 9000 Line (Cu Electroplating Sn/Pb Electroplating, Resist Strip and Etching



Day	C(mg/l)	Q(l/h)
1	0.6	-
2	-	677
3	18.9	373
4	20.8	314

Day	C(mg/l)	Q(l/h)
1	1.5	-
2	-	228
3	50.0	368
4	48.5	402

Day	Q(mg/l)
1	3610
2	2350
3	2080
4	2240
5	2220

Day	C(mg/l)	Q(l/h)
1	-	-
2	-	-
3	37.2	417
4	39.6	368
5	-	

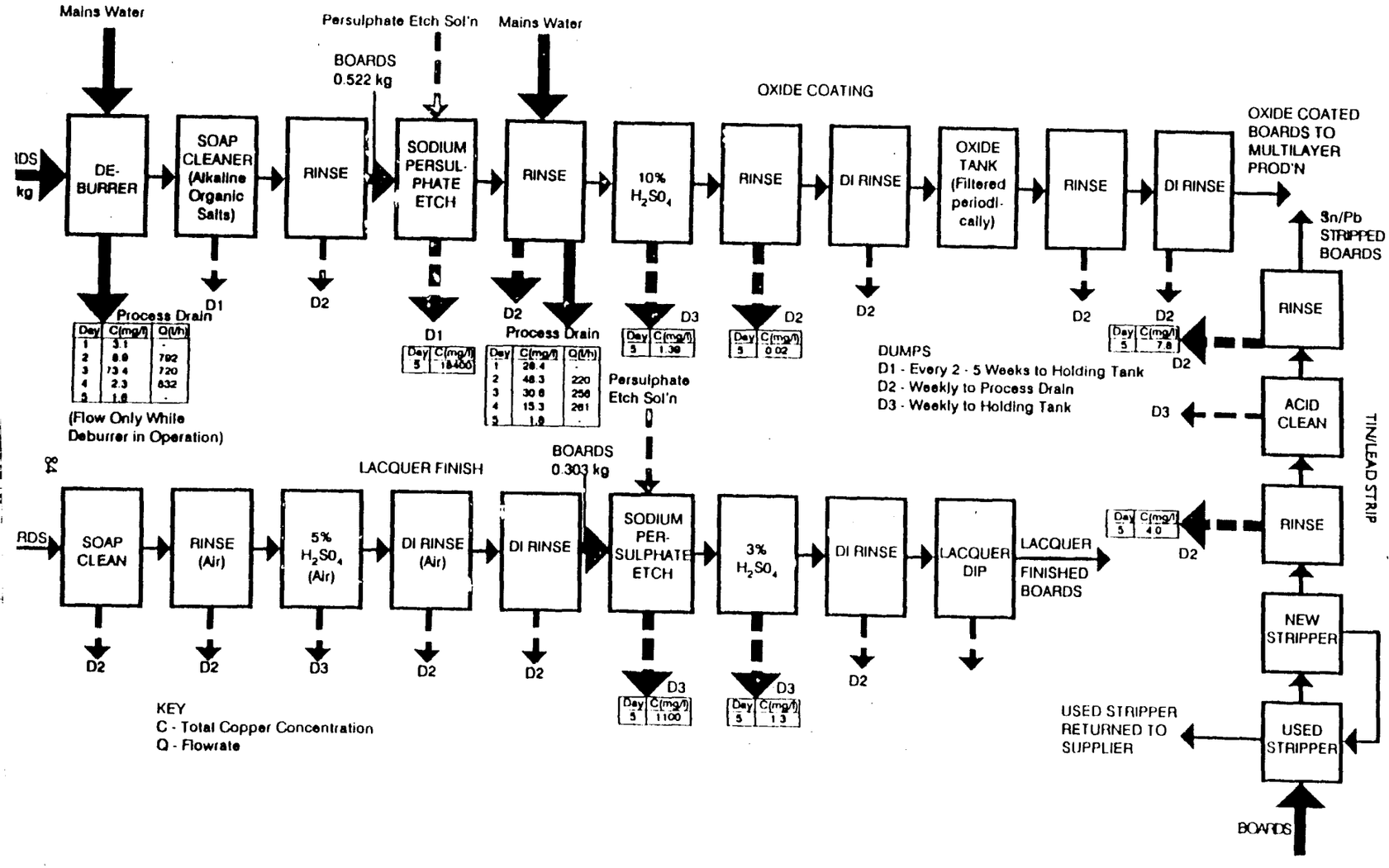
Day	C(mg/l)	Q(l/h)
2	17620	1080
3	16820	1080

Day	C(mg/l)	Q(l/h)
2	22600	1080
3	21300	1080

KEY
C - Total Copper Concentration
Q - Flowrate

DUMPS
D1 - Daily to process sewer
D2 - Monthly to holding tank
D3 - Daily to holding tank
D4 - Change filters quarterly

Figure 5: Process Flow Diagram for Oxide Coating, Lacquer Finish and Tin/Lead Strip



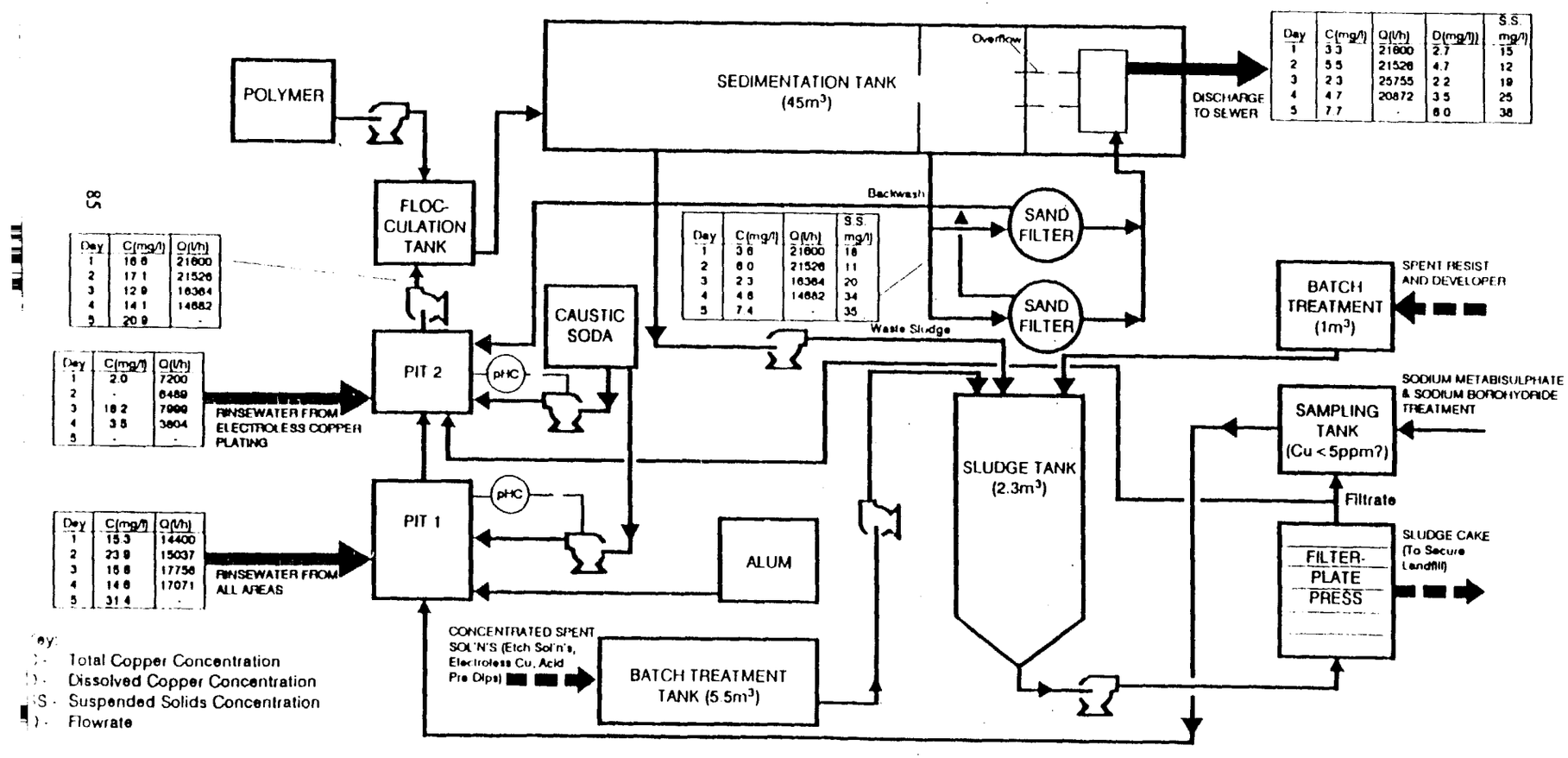


Figure 6: Process Flow Diagram for Wastewater Treatment Plant

PHASE 2: MATERIAL BALANCE: PROCESS INPUTS AND OUTPUTS

Due to the relative complexity of the printed circuit board plant the inputs and output information collected for the unit operations were recorded on the process flow diagrams based on Steps 4 - 10 of the waste audit manual. Any areas of inefficient operation and any opportunities for waste reduction were also noted. These opportunities are discussed later in Steps 15 -18.

Step 4: Determining Inputs

Input information was obtained from measuring chemical additions and water use and recording the area of copper circuit boards processed (etched);etching of the copper circuit boards involves acid treatment for surface conditioning, or finishing, and represents a significant copper input. In the case of the electroplating line the weight of copper anode used (the source of copper for electroplating) was estimated from past data. The wastewater treatment plant inputs were determined by measuring the total wastewater flows and concentrations.

Copper input information for the five processing areas was then recorded on the process flow diagrams in Figures 2 - 6.

Due to the nature of the copper raw materials (copper sulphate solutions and copper laminated boards) no handling losses were considered to occur prior to the processing operations.

Step 5: Recording Water Usage

The rinsewater flowrates were measured at the inlet to the rinse tanks by measuring the time to fill a known volume container or by draining down the rinse tanks and measuring the time to refill. The company had recently installed flow restrictors on the rinsewater feed pipes, a good water conservation measure, in order to limit the amount of water being used in the rinsing operations. In general, the flowrates measured were in accordance with the ratings for the flow restrictors.

The water usage data was also recorded on the process flow diagrams (Figures 3 - 6).

Step 6: Measuring Current Levels of Waste Reuse/Recycling

Copper-containing wastes were not generally reused at the plant. However, there was an on-line crystalliser on the sulphuric/peroxide etch stage of the electroplating line. The etch solution is pumped from the etch tank through the heat exchanger and into the copper sulphate crystalliser where the spent etch solution is cooled to 16°C. Copper sulphate crystals are precipitated and then conveyed to storage tanks, drained and subsequently sold to a local plating shop. The recovered etch solution is returned to the etch feed tank. The quantity of etchant reused is described as an input in Figure 4.

Step 7: Quantifying Process Outputs

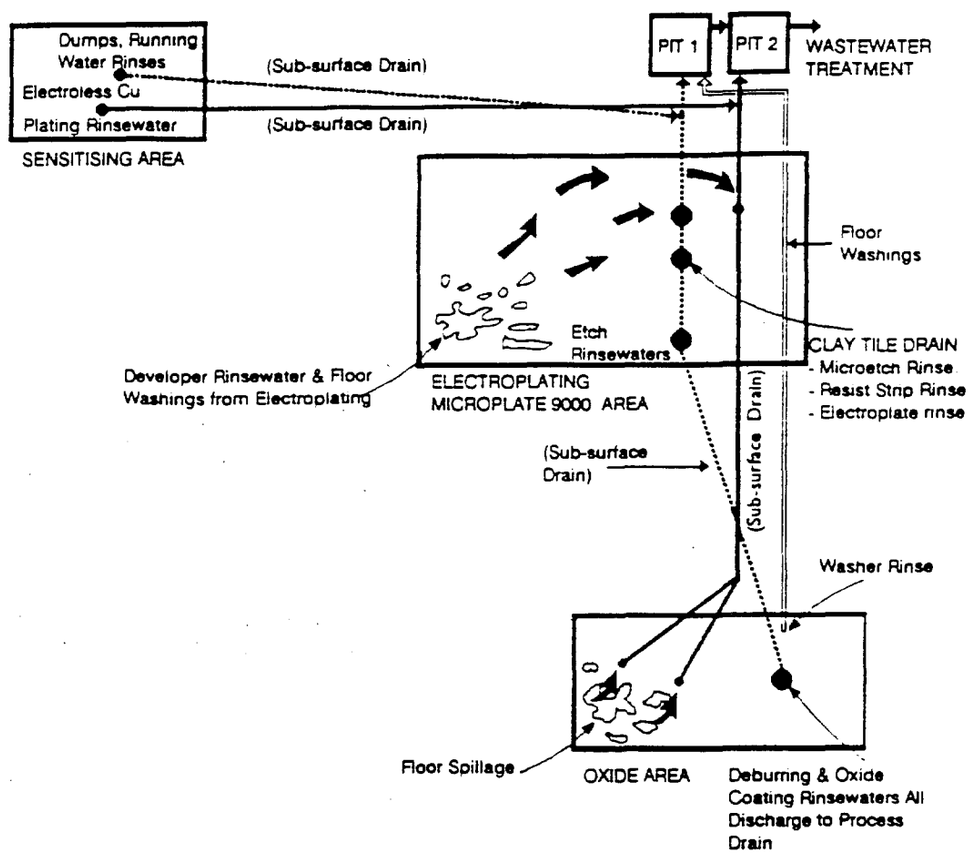
The copper-related process outputs were identified and then quantified from copper plating records and the measurement of waste masses, volumes and concentrations. Apart from the quantity of copper plated on to the printed circuit boards, which was determined from production information and plating thickness used, the process output information was obtained from measurements taken in the plant.

Step 8: Accounting for Wastewater

All the wastewater streams which were identified as containing copper (from Steps 1 and 7) were investigated in a thoroughly planned and conceived sampling programme. The sampling was performed over a production week in order to cover the full range of operating conditions and to ensure representative data. Composite samples were taken for all running wastewater streams whereas spot samples were obtained in the case of bath tanks and dumpings. Samples were also taken of the outputs from the wastewater treatment plant. The samples were carefully labelled, logged and sent out to an independent laboratory for copper and supporting analyses. Wastewater flows and tank volumes were also recorded. The wastewater information is described in Figures 2 - 6.

In addition, a process flow diagram describing the layout of the process drains was constructed (Figure 7). Dye tests were performed to determine the fate of the wastewater streams and the layout and interconnections of the surface drains. These studies highlighted some unnecessary and complex rinsewater piping arrangements which were subsequently modified by plant engineering staff.

Figure 7: Layout of Process Drains



Step 9: Accounting for Gaseous Emissions

The site investigations indicated evidence of a number of gaseous emissions. These were largely associated with forced-ventilated fume hoods to remove air-borne particulates from grinding operations and also acid and solvent fumes from subsequent process areas.

As wastewater issues were considered to be of priority concern for the current waste audit, it was decided that gaseous emissions would be a subject for further study at a later date.

Step 10: Accounting for Off-Site Wastes

The quantity of waste material stored on site and transported off-site for disposal was estimated from in-plant investigations and study of company records. The registerable wastes disposed of off-site included copper fines (270g/100m^2 of board), cartridge filters, and filter-press cake (1360 kg/week). The tin lead activator dump (0.7 m^3/annum) was stored on-site as registerable liquid waste.

Step 11: Assembling Input and Output Information for Unit Processes

The material balances were started by assembling the complete input and output data, converted to standard units, on the process flow diagrams (Figures 2 - 6).

Step 12: Deriving a Preliminary Material Balance for Unit Processes

From the collated information the preliminary balances were constructed for each processing area.

a) Sensitising Deburrer

The deburrer located in the sensitising area is operated in a recycle mode (see Figure 2). Return water is continuously filtered to remove copper fines before being fed back to the deburrer. Captured copper fines are subsequently backwashed from the sand filter and collected in the bag filter. Essentially the copper inputs are from the brushed boards and the outputs are from the sand filter backwash bag filter and the cartridge filter. An accurate mass balance could not be constructed from the available information as the thickness of copper removed from the boards could not be determined precisely. However, the company did plan to purchase a high-resolution microscope in the near future which would enable accurate determination and control of copper thicknesses removed.

b) Sensitising (Electroless Plating)

The preliminary material balance for the electroless plating line is shown below.

Copper Inputs (kg/week)	
Copper fines from deburrer	0.040
Boards (microetch)	30.700
Etch solution	3.000
Electroless plating solution	25.000
Total	58.743

↓

Electroless Plating

↓

Copper Outputs (kg/week)	
Boards (plated)	21.283
Rinsewaters	4.867
Dumps	0.261
Microetch dump	29.000
Electroless copper (storage)	4.400
Total	60.811

c) Electroplating Line (Microplate 9000 line)

Copper Inputs (kg/week)	
Boards (microetch)	0.667
Boards (sulphuric/peroxide etch)	209.586
Copper anodes	124.500
Return etch solution	743.904
Total	1078.657

↓

Microplate 9000 Line

↓

Copper Outputs (kg/week)	
Boards (plated)	100.078
Rinsewaters	1.474
Dumps	0.523
To etch recover (18 l/min) including 217.000 kg crystallised copper)	948.240
Total	1050.315

No make-up or dump of the sulphuric acid/peroxide etch tanks was made during the study period and as the crystalliser maintains a constant copper concentration in the etch tank these inputs and outputs were not considered in the material balance study.

d) Oxide coating area

Copper Inputs (kg/week)	
Boards (deburring)	0.653
Boards (microetches 10×10^{-6} inch)	0.825
Total	1.478

↓

Deburrer, Oxide Coating and Lacquer Finish

↓

Copper Outputs (kg/week)	
Rinsewaters	0.195
Dumps (drain)	0.003
Dumps (holding tank)	0.311
Copper fines (to drain)	0.632
Estimated copper increase in oxide Microetch bath	0.347
Total	1.488

e) Wastewater treatment

Copper Inputs (kg/week)	
Pit 1 Influent	12.493
Pit 2 Influent	12.893
*Concentrated spent solution	1.095
Total	26.481

↓

Wastewater Treatment System

↓

Copper Outputs (kg/week)	
Sewer discharge	5.239
Filter-plate press sludge (Estimated by difference)	21.242
Total	26.481

* No concentrated copper solutions treated in the study period

The volume of the filter-plate press sludge was estimated by difference as the sludge was withdrawn from the clarifier on an irregular and infrequent basis.

In addition, a material balance was constructed from all the rinsewaters and daily dumps to the process drains and the feed to the wastewater treatment system over days 1 - 4. (This mass balance primarily represents the rinsewaters as most of the dumps are carried out on day 5.)

Copper Inputs (kg)	
Rinses	
Sensitising	
Alkaline cleaner rinse	0.014
Microetch rinse	4.404
Acid rinse	0.115
Electroless	0.259
Acid rinse	0.019
Electroplating Line	
Mircoetch	0.191
Floor capture	0.276
Electroplating	0.607
Etch rinse	0.600
Oxide Area	
Deburrer	0.653
Etch	0.025
Dumps	
Electroplating Line	
Mircoetch rinse	0.048
Electroplate rinse	0.235
Etch rinse	0.180
Total	8.346

↓

Drains

↓

Copper Outputs (kg)	
Treatment plant influent (total)	9.192

Step 13: Evaluating the Material Balance

Each material balance drawn up showed a good agreement considering the complexity of the printed circuit board manufacturing plant and the large number of waste copper sources. Approximately 91 percent of the copper loading into the treatment plant during production days 1 - 4 was accounted for by the measured wastewater sources. The extra 9 percent was probably due to copper being washed from contaminated floor areas and further minor sources of copper which were not included in the survey (eg gold plating line).

PHASE 3: SYNTHESIS

Step 14: Refining the Material Balance

The preliminary material balance work, while giving very satisfactory results, had included a number of assumptions and estimates (by difference) had to be made: this particularly applied to the oxide-coating and wastewater treatment areas. A decision was therefore made to refine the material balance backing up the estimates by further monitoring and information gathering.

Step 15: Examining Obvious Waste Reduction Measures

From the information accumulated from the waste audit and observations which were made while investigating the plant in detail a number of obvious waste reduction and efficiency improving measures were identified. These again split into the four processing areas and the wastewater treatment plant.

a) *Deburring operations (sensitising area)*

It was noted that the sand filter associated with deburring operations was backwashed with return (dirty) water which would lead to entrainment of copper fines throughout the sand bed. This could lead to fines being released into the filtered water. The deburred spray water had a suspended solids concentration of 104 mg/l. This high concentration probably accounted for the fine powder layer which was observed on the printed circuit boards after the deburrer drier. While this only represented a small input of copper into the sensitising line (0.04 kg/week), it created a potential adverse effect on product quality control.

The waste copper fines which were collected on the backwash bag filter system (2.6 kg per 3 days production) are transported to a secure landfill site together with sludge cake from the filter press. However, the fines are relatively pure copper and investigations confirmed them to have a value of approximately US$0.9/kg corresponding to a small potential income of US$275 per annum.

b) *The sensitising line (electroless plating)*

As discussed previously, the results of the wastewater characterisation showed that a very high copper loading was from the microetch rinse (90 percent of the sensitising rinsewater copper load). The sensitising line is a manually-operated plating line and it was observed that no drip time was used after the microetch. A one minute drip time was thus introduced and a monitoring programme initiated to record improved waste loadings. It was subsequently concluded that a static-rinse drag-out tank should be installed in the longer term to reduce further the running rinsewater loading from this source.

c) *Electroplating line*

It was noted that the recirculation pumps on the copper electroplating line had leaking mechanical seals leading to copper crystallisation on the pump shafts and surrounding floor areas. This copper material was subsequently picked up by the developer rinse, which flowed directly onto the floor, and discharged to the floor drain leading to Pit 12. The copper loading from this source at one floor drain closed to the electroplate rinse was approximately 70 g/d.

It was considered that although this pollution load passing to a drain was small, a satisfactory maintenance programme to prevent all such leaks and installation of drip trays and general cleanliness in the copper electroplating areas could reduce this source of waste loading on the treatment plant. Good housekeeping in all copper processing and handling areas could prevent copper waste loading from other areas (eg copper etch and crystallisation) from reaching the drain system.

d) Oxide coating area

The rinsewater from the deburrer in the oxide coating area was discharged directly to the process drain. A bag filter was attached to the pipe at the outlet to the drain but during the in-plant study the capturing device was inefficient leading to significant quantities of copper fines being released to the drain system. Contact with acid wastewaters would subsequently dissolve the fines in the process drains. Using existing equipment stocks, a closed-loop filtration system similar to the one in the sensitising area was added as a relatively simple control measure, eliminating this source of waste copper.

e) Wastewater treatment system

A number of inefficient operations in the wastewater treatment system were highlighted in the waste audit. First, alum was added to the pH corrected (pH 8.5) wastewater in Pit 1. Alum is an effective coagulant for colloidal material but is not necessary for metal hydroxide precipitation and increases the volume of sludge produced.

Second, the existing sedimentation basin was of poor design. Inadequate sludge removal capability and floating sludge were creating effluent discharge problems.

Third, in an effort to overcome the periodic high levels of copper being discharged to the public sewer, two sand filters were installed in parallel after the sedimentation tank. However, from the results in Figure 6 it can be seen that the sand filters were not effective in removing suspended solids or copper from the wastewater.

Assuming a 50 percent reduction of copper loading from the sensitising microetch rinse through improved rinsing, and elimination of the copper loading from the deburrers and electroplating area floor drain, a 40 percent reduction in rinsewater loading to the wastewater treatment plant could be achieved.

Step 16: Targeting and Characterizing Problem Wastes

From Figure 6 it can be seen that the sand filter input concentrations of suspended solids and copper are approximately equal to the output concentrations from the filter. Furthermore, the copper discharged to the public sewer was primarily dissolved (75 - 95 percent of total copper concentration) and in excess of the sewer discharge limits on days 2 and 5. Previous experience with the treatability of the printed circuit board wastewaters had established that the electroless copper wastewaters were particularly difficult to treat because of the presence of chelating agents

in the electroless copper plating solution. In addition, chelating agents were present in the resist stripping solution. It was noted that when the treated resist strip was dumped to Pit 2 on days 2 and 4, significantly higher copper concentrations were observed in the discharge to the public sewer than on days 1 and 3. Day 5 (Friday) represents an atypical waste treatment day as weekly dumping of tanks in the sensitising and oxide areas occurs on this day.

The chelate containing copper wastewater and combinations of copper and chelate containing wastewaters were therefore considered to be 'problem wastes'.

Wastewater treatability tests using alum, sodium hydroxide, lime and a range of flocculants were conducted on samples from each individual pollutant source and on combined samples. The tests indicated that most copper containing wastewaters could be treated very successfully by metal hydroxide precipitation. However, the chelating agents in the electroless rinse and resist strip rinse affected copper hydroxide precipitation and should therefore be segregated and treated separately.

As indicated in Table 1, the tests on the influent wastewater treatment plant indicated that copper could be reduced from relatively high concentrations to less than the 5 mg/l standard using lime and anionic polymer flocculant. In general, lime produced a more dense and settleable precipitate than sodium hydroxide although it generated more sludge.

Table 1: Treatability Tests using Lime and Anionic Polymer

Sample	Raw/Treated	Total Copper in Supernatant (mg/l)
Sensitising		
Microetch rinse	Raw	260.0
	Treated	0.3
Electroless rinse	Raw	9.1
	Treated	9.0
Electroplating Line		
Microetch rinse	Raw	22.0
	Treated	0.2
Copper electroplate rinse	Raw	33.0
	Treated	0.2
Copper electroplate rinse Resist strip rinse (50:50)	Raw	19.0
	Treated	20.0
Electroplate floor drain	Raw	44.0
	Treated	0.1
Sulphuric/peroxide etch rinse	Raw	40.0
	Treated	0.1
Oxide Coating		
Microetch rinse	Raw	150.0
	Treated	1.1
Wastewater Treatment		
Influent	Raw	11 74 13 73 8.4*
	Treated	0.4 0.6 0.4 4.0 0.7

*Hourly spot samples

Step 17: Segregation

It was clear from the findings of the waste audit investigations that waste segregation would form a necessary part of any long-term waste reduction programme in order to develop a technically satisfactory and cost-effective system. This aspect will be described in Step 18 below.

Step 18: Developing Long-Term Waste Reduction Options

While the waste reduction alternatives described in Step 15 will reduce pollutant loadings and result in significant cost savings, an efficiently designed and operated end-of-pipe treatment

section describes the wastewater treatment and recovery system design which was developed from the waste audit and treatability studies with the assistance of a consultant engineering company.

The major points for consideration in the system design were as follows.

- Segregation of all the chelate-containing wastewaters from the conventional metal hydroxide precipitation system.
- Segregation and separate treatment/recovery of all the chelate-containing rinsewaters and concentrated bath-dumps.
- Collection of all general bath dumps (non-chelate containing) in a holding tank for metering back to the conventional treatment system at a controlled rate (to prevent surges in copper loading).
- Upgrading of existing pH adjustment, polymer addition, clarification and sand filtration systems for efficient metal hydroxide precipitation and subsequent discharge of high quality effluent.

Information on the type of chelator or chelate concentration was not readily available from the chemical suppliers.

The sources of chelate containing wastewaters were as follows:

Source	Flowrate (l/h) or Volume (litres)	Copper Concentration (mg/l)
Mild Alkaline Cleaner Bath	400 litres	63.7
Mild Alkaline Cleaner Rinse	518 litres	0.8 (max 1.7 mg/l)
Electroless Plating Bath	588 litres	11000
Electroless Plating Bleed	10 l/h	11000
Electroless Plating Rinse	770 l/h	7.7 (max 10.3 mg/l)
Resist Strip Bath	920 litres	Less than 5.0
Resist Strip Rinse	390 l/h	

The proposed treatment system incorporates the following key elements.

- Collection of all non-complexed rinsewaters in a common sump for pH adjustment with caustic (or lime) to pH 9.0 - 9.5.
- Installation of a static-rinse tank after the electroless copper plating bath. The static-rinse tank will collect most of the drag-out loading from the electroless plating bath and will then be dumped daily for electrolytic recovery. The subsequent continuous-flow rinsewater (chelate-containing), operated on a counter-current principle, will then be discharged directly to the public sewer.
- Segregation, cartridge filtration and direct discharge of resist strip rinsewaters (chelate-containing) to the clarified water storage tank.
- Segregation and direct discharge of electroless plating running rinsewaters and cleaner rinsewaters (chelate-containing) to the clarified water storage tank.

- Segregation and collection of resist strip and developer dumps (or bleed) in a separate holding tank for pH adjustment and direct discharge.
- Segregation and collection of electroless copper (chelate-containing) bath dumps, controlled bleed and drag-out tank contents together with alkaline cleaner (chelate-containing) and microetch (sensitising) bath dumps in a separate batch recirculation tank for electrolytic copper recover. Possible alternatives involving sulphide precipitation or sodium borohydride treatment were also considered but discounted on technical and cost grounds.
- Polishing of electrolytically treated solutions in a chelating ion exchange resin bed prior to discharge to the clarified water storage tank.
- Segregation and collection of general bath dumps (eg microetches, predips, acids, alkalis, etc.) in a holding tank for subsequent metering into the pH adjustment sump.
- Modification of the existing sedimentation tank to incorporate a clarified water storage tank and provision for capture of accidental spills and emergency waste storage.
- Provision of an inclined-plate clarifier following existing pH control and flocculation units with sludge pumped to a sludge storage/thickening tank. Thickened sludge will then be periodically pumped from the storage tank for dewatering in the filter-plate press. The reduced volume of sludge cake will then be disposed of in a secure landfill site.
- Although it is considered that the effluent copper concentration from the proposed treatment system will comply with the existing discharge standard of 5 mg/l, it was recommended that the company's sand filters be upgraded and included in the treatment scheme in anticipation of the proposed lowering of the standard to 2 mg/l of copper. In this case, the clarified wastewater should be polished through a sand/anthracite dual-media bed to increase the solids loading capacity of the filters.

Step 19: Environmental and Economic Evaluation of Waste Reduction Options

As Company C was facing legal action from the local authority with respect to violation of discharge standards, the return on investment was not of prime concern in this case study; of more importance was the development of the most cost-effective reduction/waste treatment system available, and a quality of final effluent for sewer discharge compatible with the local authority's environmental pollution control requirements.

From Step 18 a number of waste treatment recovery alternatives were identified and a process design subsequently derived on the basis of technical considerations. However, through the waste reduction opportunities described and the segregation and recovery of copper from the chelate-containing and microetch (sensitising) wastes it was estimated that a cost saving of US$22,000 per annum on sludge transportation and secure landfill disposal costs could be realised. In addition, it was estimated that approximately US$3,500 per annum of copper could be recovered using the electrolytic recovery unit.

The total installed cost of the proposed system including the major equipment items (inclined-plate clarifier, sludge storage/thickening tank, filter-plate press, electrolytic copper recovery unit,

IDENTIFYING POLLUTION PREVENTION OPTIONS

National Pollution Prevention Center
for Higher Education

Doc # 94-3
March 1994

CASE STUDY

Environmental
Engineering

Degreaser Replacement at Ford Motor Company's Climate Control Division

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BACKGROUND

Ford Motor Company's Climate Control Division (CCD) recently completed a demonstration project with the Quality Environmental Management (QEM) Subcommittee of the President's Commission on Environmental Quality (PCEQ). The project demonstrated how pollution prevention and Total Quality Management (TQM) work together to reduce the environmental impact of a process, while at the same time providing a product that meets customers' needs. The pilot project undertaken by the CCD tested the replacement of Trichloroethylene (TCE) degreasers with aqueous degreaser units.

The CCD uses degreasers to remove oils and other contamination from aluminum heat exchangers found in radiators and heater cores. Heat exchangers are manufactured from stamped aluminum. In the stamping and assembly processes, oils are used to get the desired shape and fit. These processes deposit aluminum and dirt particles along with a surface oil residue. During assembly, heat exchangers are brazed to form an aluminum film which joins the different components of the part. To be brazed properly, the part must be as free of contamination as possible. Therefore, some sort of degreasing operation is required to decontaminate the part. Previously, TCE vapors were used to remove the oils and other contaminants from the part. **Figure 1** shows TCE vapor degreasing units previously used by CCD.

This degreasing process had many inherent problems. To begin with, TCE is a hazardous substance whose emissions are closely regulated. The TCE degreasers required close supervision

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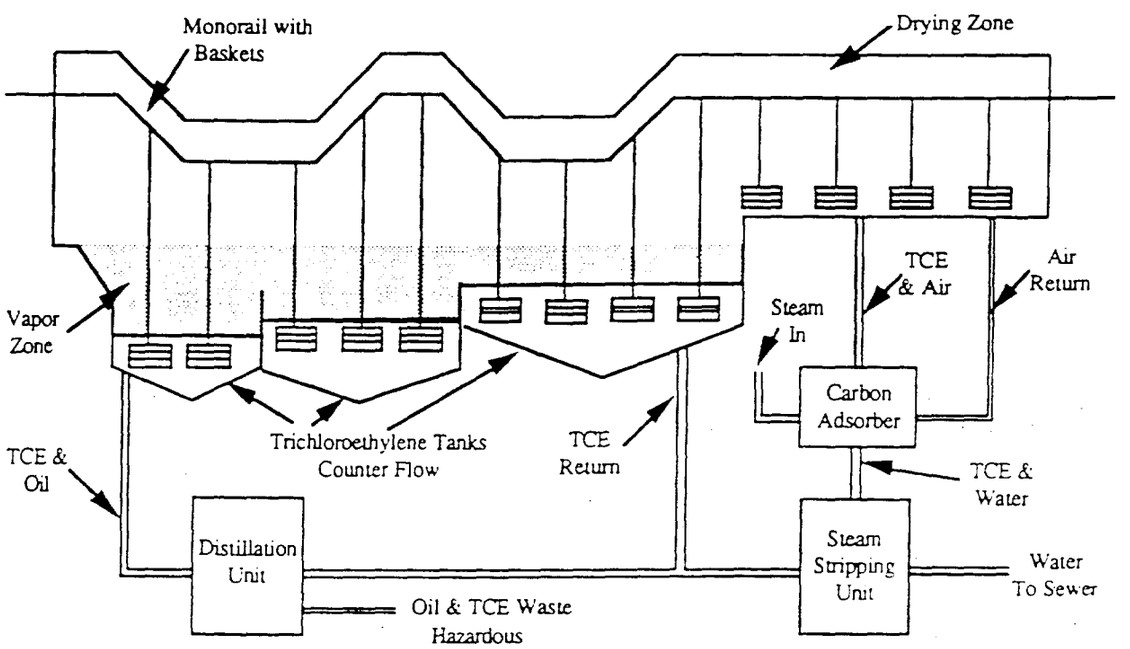

Figure 1. TCE Vapor Degreaser Unit

from a team of skilled operators. Additionally, the escape of TCE vapors from a degreaser almost always required a costly evacuation of the production facility and could potentially shut down operations for a number of hours. Finally, there were questions about TCE's effectiveness in removing contamination from the surface of the parts.

AQUEOUS DEGREASING SELECTION PROCESS

The CCD Advanced Engineering (AE) Staff designs and tests new processes and technologies that could improve existing operations, and it also develops manufacturing techniques for new products. AE is guided by a steering committee of representatives from its customer base, which includes CCD facilities worldwide, product engineering staff, manufacturing engineering staff, and division management. The steering committee sets the goals, priorities, and resource commitments for all AE Staff projects.

In early 1990 the AE Staff, along with the steering committee, realized that worker health and safety could be improved by replacing TCE degreasers with a less hazardous

process. Such a substitution could also reduce environmental costs. As Ford corporate staff identified the sources of solvent releases in the U.S., the AE Staff realized that CCD's TCE degreasers accounted for a substantial portion of the entire company's chlorinated solvent emissions.

Investigation of a new brazing technique contributed to the replacement of TCE degreasers. In the new process, the surface of the heat exchangers degreased with TCE required additional preparations. Despite this, the new technique was attractive because it offered CCD a better, simpler braze compared to the current process, especially if an improved degreasing operation could eliminate much of the additional preparations. Finally, CCD anticipated that a new degreasing process would reduce production costs.

At the time of the initial decision to explore alternate degreasing techniques, the AE Staff integrated quality techniques into their project evaluation process through a process evaluation flow chart. They later realized they were also working on a pollution prevention project, aimed at lowering the toxicity of the degreasing process.

CCD's AE Staff committed an engineer to the project to decide which technology should be tested as a potential replacement for the TCE degreasers. As a starting point, CCD's degreasing operation was benchmarked against similar operations. Benchmarking researches techniques currently used by other companies involved in similar operations and establishes a scale for comparing and contrasting alternatives in order to identify areas of improvement. One can thus compare one's own process to others as well as learn what other experimenters have determined to be feasible processes. Benchmarking also offers the opportunity to avoid costly mistakes that others may have already committed. As can often be the case, the technique was limited by the fact that CCD competes for business against outside suppliers. As a result, it was often difficult to get detailed information about how competitors were undertaking a particular operation.

Even so, benchmarking helped identify a number of technologies that merited further investigation. For those technologies, prospective equipment and chemical suppliers were asked to submit further information about their products. Bench testing of available chemicals was also performed to ensure compatibility with the aluminum. Along with benchmarking, this initial testing led the engineer and the steering committee to choose aqueous degreasing for pilot testing.

Once aqueous degreasing was selected, the engineer had to select what type of cleaning process should be used. Three choices were available:

1. Immersion cleaning
2. Ultrasonic cleaning
3. High pressure spray cleaning

Immersion cleaning and ultrasonic cleaning were eliminated from the potential list because they were either incompatible with the heat exchangers or they were not yet a reliable technology.

High-pressure spray represented the best aqueous technology because most of its effectiveness derives from mechanical rather than chemical action.

Because pilot testing requires a production setting, CCD selected its Sheldon Road plant in Plymouth, Michigan to be the test site. This plant is within twenty miles of most of the company's research and engineering resources. Plant personnel would be involved with the equipment at their site, so they were asked to participate in the evaluation process. At this point, a Quality Action Team (QAT) was formed to facilitate the flow of information between individuals working on the project, including the Advanced Engineering Staff, the division representatives, the plant representatives, and the suppliers.

To ensure that the plant would not suffer financial detriment by hosting the pilot study, funds were allocated to cover any maintenance expenses and to pay the Sheldon Road employees to act as loaders and unloaders on the test apparatus. Because plants are held financially accountable for their operations, they are usually unwilling to take risks which may hurt profitability. But when division or corporate management is willing to bear the risk, company operations are more willing to try something new. Corporate assumption of financial risk has been used throughout Ford as a means to initiate a number of pollution prevention programs.

After selecting the high-pressure spray aqueous degreaser, a small-scale trial was conducted at an equipment supplier's facility. This trial validated the compatibility of the technology and also offered an opportunity to test some of the available cleaners in a "production type" system.

AE then conducted its own trials using a bench scale washer to replicate the production process. By setting up a bench-scale washer, CCD was able to avoid many of the expenses that could arise if a mistake occurred during production. The first advantage to working in bench scale is that the technology can be evaluated with a minimum investment. Should the technology prove inadequate, it can be abandoned at this point without a major loss. The second advantage of using bench-scale testing is that a wide variety of substances can be tested without incurring large costs, especially from wasted samples. What often happens is that a drum of material is purchased and a sample from it is tested. If the material is unsatisfactory, it must either be returned to the supplier (if they will accept it) or properly disposed, which is often rather expensive. But when bench-scale testing is performed, a five gallon pail of the material will normally be sufficient, and such small a quantities are often provided gratis by sales representatives. Testing then consumes all the material or leaves such a small volume of unused product that proper disposal is not difficult.

The aqueous degreasing program also requires a cleaner, so approximately a dozen different chemicals were evaluated for this purpose. The cleaners were divided into groups based on their pH. The three groups were:

- Strong alkaline cleaners (pH > 13)
- Moderate/mild alkaline cleaners (7 < pH < 13)
- Acidic cleaners (pH < 7)

Due to the incompatible, aggressive nature of the strong alkaline and acidic cleaners, both groups were eliminated from future consideration. Of the moderate/mild alkaline candidates, testing showed that the moderate alkaline cleaners provided the best part quality. The cleaners' performance was measured using five main parameters.

1. Oxide layer thickness — An oxide layer inhibits the brazing process; therefore cleaners which promoted oxide growth were eliminated.
2. Residual carbon contamination — This offers a measure of the amount of oil removed from the part. All cleaners tested exceeded the level of cleanliness that the vapor degreaser provides.
3. Aluminum surface attack — Etching removes a portion of the aluminum cladding, which can adversely affect brazing; therefore this property was kept to a minimum.
4. Surface wetability — Surface wetability offers a measure of how well water-based brazing materials will work. All attempts were made to maximize this parameter.
5. Oil rejection and treatability — All cleaners were evaluated to ensure that they formed unstable emulsions with the oil so that the oil could be recovered. Additionally, to make the aqueous system as simple as possible, the cleaners had to be dischargeable to the sewer system without further treatment.

After these five properties were used to decrease the number of cleaners, low volume production trials were performed to rank the remaining cleaners. With the ranking established, large volume trials were conducted until a suitable cleaner was found. These production trials demonstrated that the effectiveness of the cleaners is influenced by temperature, concentration, and time of contact.

Upon completion of the low-volume production trials, a pilot system was purchased. The pilot process was a scaled-down version of the production system. The degreasing unit featured three-stage processing, with individual stages for a pre-wash, a detergent wash, and an overflowing rinse. The equipment included blowers to minimize drag-out and cross contamination between stages. Attached to the prewash was an oil decant system capable of recovering more than 99% of the free oil without the use of chemicals. Finally, the system contained a drying unit to remove all moisture from the part. The pilot unit was capable of washing 100 radiators per hour, a fraction of the production level. The unit was installed at Sheldon Road in January of 1992, two years after the start of the project. As testing progressed, evaluation of cleaners continued. Some of the cleaners which performed well in small trials were unable to withstand production conditions and had to be eliminated. **Figure 2** is a schematic of the pilot system.

System characteristics of the pilot unit were monitored and recorded. These data were used to determine operating costs, chemical usage, control requirements, waste treatment issues, utility usage, and best operating practices. The data allowed AE to tell its facilities what was involved with the new process and predict the costs of operating a production unit. These data also confirmed that the basic goals of pollution prevention were achieved.

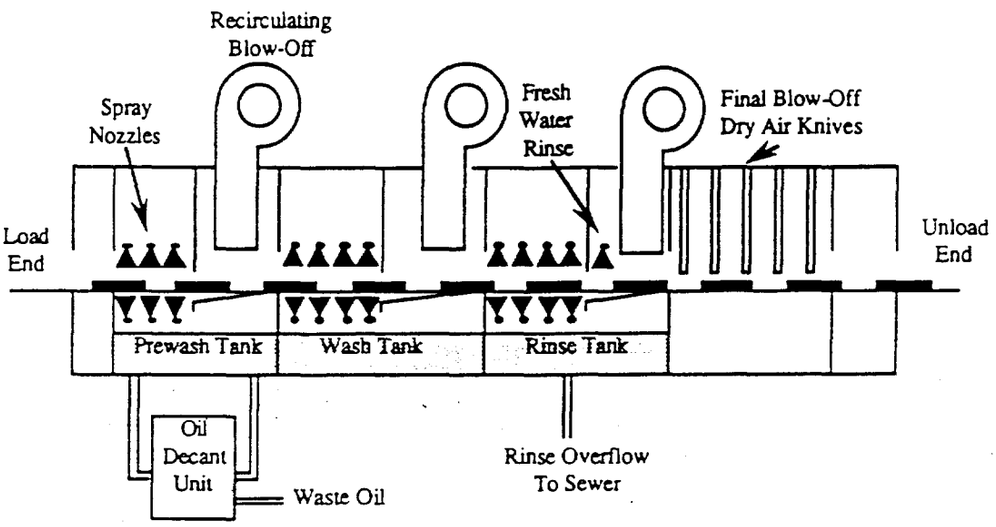

Figure 2. Pilot Aqueous Degreaser System

The pilot testing, completed in July 1992, demonstrated the success of aqueous degreasing. The aqueous system proved that it provided more cleaning at a lower cost than the TCE vapor degreasing system. By changing the process, a hazardous substance was removed from the plant, improving both health and safety as well as the plant's environmental impact. Plus, it was possible to recover the used oil for reclamation. Finally, the pilot work showed that aqueous degreasing is an easily controlled process.

The equipment used in the pilot process was returned to the manufacturer for retrofitting. After this, the machine entered full production at CCD's Connersville, Indiana plant. Monitoring will continue to provide long-term data on the process. Improvements will also be tested, including an examination of ultrafiltration to enhance emulsified oil recovery and decrease cleaner usage.

The President's Commission on Environmental Quality

Ford Motor Company joined the President's Commission on Environmental Quality in 1991 and was active on the Quality Environmental Management (QEM) subcommittee. The subcommittee was charged with developing procedures that companies can use to implement QEM. In order to carefully develop the procedures, twelve projects from eleven companies were solicited to act as demonstration projects. The leaders of these projects were required to describe their quality process and how they measured results. They were also asked to identify barriers and incentives to

QEM and pollution prevention. Ford selected the aqueous degreaser project when asked to provide a demonstration project.

The PCEQ had previously developed a theoretical flow chart outlining the procedures a company should use to undertake pollution prevention projects. The PCEQ flow chart, shown in **Figure 3**, closely resembles a standard Total Quality Management (TQM) flow chart. Because Ford had been using quality principles for a number of years, the process evaluation flow chart used by CCD AE also closely resembled the PCEQ flow chart.

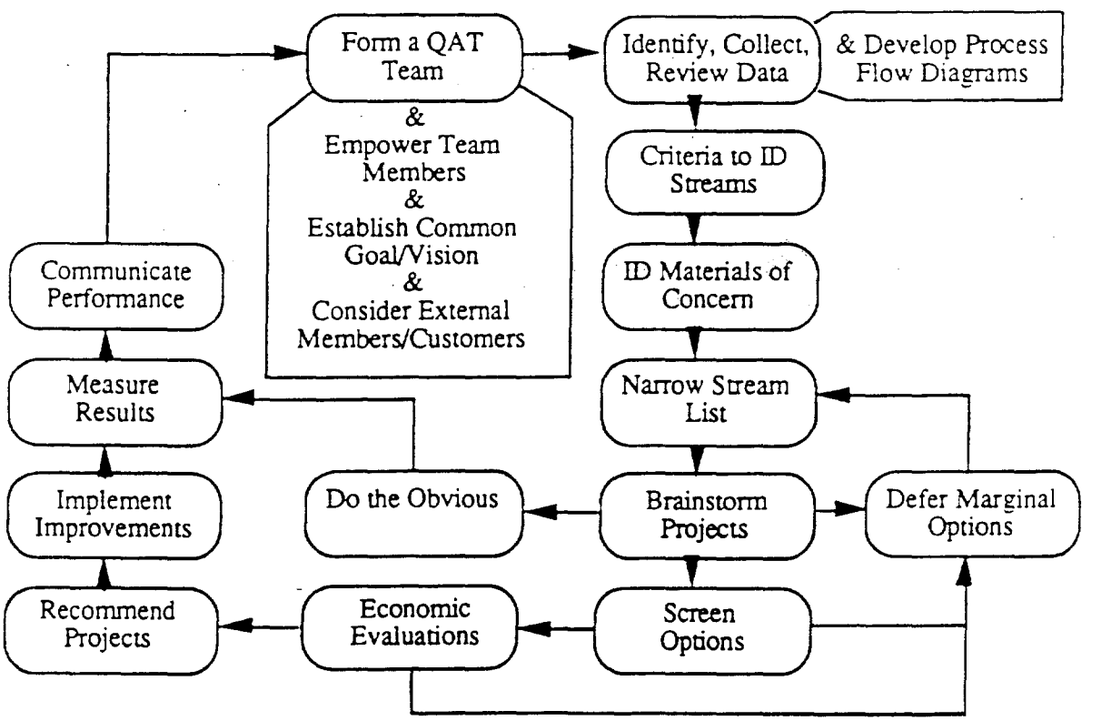

Figure 3. PCEQ Flow Chart

The PCEQ demonstration project began in the middle of the aqueous degreaser pilot project. Therefore much of the information gathered for the PCEQ was generated under normal conditions and not affected by the attention the PCEQ brought to the project. Because the PCEQ project at Ford was guided by the Chairman and Chief Executive Officer, Harold Polling, and the

Vice President for Environmental and Safety Engineering, Helen Petrauskas, resources that normally would not be available were dedicated to this project.

Forming cross-functional teams is the first step in any TQM endeavor. These teams are referred to by the PCEQ as Quality Action Teams (QAT). A QAT is supposed to use all the knowledge and resources available to team members. Ideally, this pooled insight helps the team avoid many of the pitfalls that can occur in projects relying on a narrow range of expertise. QAT members should include all stakeholders in a project, whether they are customers, engineers, product designers, vendors, or others.

Advanced Engineering normally forms QATs with representatives from vendors, the plants, the division, and other necessary resources such as the Research Laboratory. Due to the sensitive and technical nature of process modifications, public representatives usually do not participate in the decision-making process. But because of the attention brought to this project by the PCEQ, community members were invited to join the team. The State of Michigan Office of Waste Reduction Services and the Southeastern Michigan Council of Governments both provided representatives. The QAT was very pleased to have these representatives, who provided a community perspective and valuable technical assistance. By viewing the community as a customer, Ford has shown there is a great potential for mutual benefit in such projects.

The high-profile nature of this project undoubtedly energized the QAT. The enthusiasm of Helen Petrauskas especially encouraged others, reinforcing the belief that a project has a greater chance of success with the support of management. Experience seems to indicate that top management support is also critical to the success of pollution prevention projects.

Ultimately, Ford's experience with the aqueous degreaser project was combined with the eleven other projects to provide a blueprint for other companies to follow. One of the most important findings is that pollution prevention and TQM are complementary activities. A second finding is that a financial incentive such as pollution credits would hasten the pace of pollution prevention projects.

In January 1993, the PCEQ issued a report, entitled *Total Quality Management: A Framework for Pollution Prevention*. Using the experiences of Ford and the eleven other participating facilities, the report provides a guide for companies interested in developing their own pollution prevention programs using TQM. Included in **Appendix A** of this report is the PCEQ Executive Summary, which highlights the twelve projects and some of the key findings.

Key findings of the PCEQ were:

- TQM and pollution prevention are complementary concepts
- Pollution prevention can be achieved without large capital investments
- There is no universal method to measure progress in pollution prevention
- Systematic and rigorous analyses are the basis for any pollution prevention project, but flexibility is required in application
- Understanding the potential incentives and barriers to a pollution prevention project can add to the success of the project (PCEQ, pp. ix-x)
- "Management commitment is crucial to the success of a QEM system" (PCEQ, p. 16)

A successful pollution prevention program using TQM can achieve many benefits. The following positive results were illustrated by the twelve PCEQ projects:

- Potential cost savings
- Advances in technological innovation
- Increased public acceptance of the facility
- Improved relationships with regulators
- Increased recognition for individuals and teams
- Safer working conditions

However, before any pollution prevention project is undertaken, one should be aware of the following barriers to using pollution prevention with TQM:

- Resources for any project are limited
- Many may prefer business as usual
- Management and employees may be unaware of the benefits of pollution prevention
- Accounting systems do not measure environmental costs or values, so the true gains of any project may not be known
- Fear of compromising product quality or production efficiency
- Technological limitation (PCEQ, pp. 8-11)

The PCEQ project has identified a number of TQM tools and techniques that helped make the twelve projects successful. These tools and techniques, currently used in most TQM programs, include:

- Cause and Effect (or Fishbone) Diagrams
- Control Charts
- Histograms
- Pareto Charts
- Flow Charts

A complete description of the different tools and techniques as well as how to implement each are included in **Appendix B**.

REFERENCE

President's Commission on Environmental Quality (PCEQ), Quality Environmental Management Subcommittee. *Total Quality Management: A Framework for Pollution Prevention.* Washington, DC: Executive Office of the President,1993.

Discussion Questions

BUSINESS

- What costs should be attributed to an existing/proposed process and how should they be accounted for?

Direct	Indirect
- Environmental audits	- Liability
- Chemical/raw material costs	- Episodic events (i.e., plant shutdowns)
- Operating supplies	- Health and safety
- Waste	- Community image
- Utilities	- Changes in quality
- Labor	- Changes in costs of processes down the line attributed to the process being evaluated
- Cleaning and maintenance	

- At what point does a project which has many positive benefits but only marginal cost savings become good for the bottom line?
- What value does increased quality have when it does not increase the value to the customer?

NATURAL RESOURCES POLICY/POLITICAL SCIENCE

- Why should companies undertake pollution prevention activities if they only yield marginal to negative cost savings?
- What value does a cleaner environment have to a company?
- Who are the customers and stakeholders to a pollution prevention project?
- What can be done to encourage pollution prevention?
- Which is better: producing a few pounds of a hazardous waste or thousands of pounds of inert waste? (e.g., a few pounds of TCE per part vs. many pounds of water per part?)

ENGINEERING

- How clean is clean in terms of part cleanliness?
- How should cost projections be made?
- How valid are the results from a pilot study?
- How would you make an aqueous washer a closed system?
- Who should be included on a cross-functional team?
- Whose job is pollution prevention? The environmental engineer's? The production engineer's? Middle management's?

Ford Case Study Problem Set With Answers

1. How many parts can be processed in a year with the pilot unit if it averages 75 parts per hour? Assume production 50 weeks a year, 5 days a week and 24 hours a day.

Parts processed per year

$$= \frac{parts}{time\ period} X\ time\ period$$

$$= \frac{75\ parts}{hour} X \frac{24\ hours}{day} X \frac{5\ days}{week} X \frac{50\ weeks}{year}$$

$$= \mathbf{450{,}000\ parts\ per\ year}$$

Pilot Unit

2a. Calculate the total volume of water used by the pilot unit in one year. The tanks sizes are:

Pre-wash tank	650 gal.
Wash	500 gal.
Rinse	500 gal.

The tanks have to be drained and cleaned once a week. The rinse tank overflows at 7.5 gpm. Assume no evaporative loses.

Total Volume = *Volume of tank fills + volume of overflow*
= *82,500 gal. + 2,700,000 gal.*
= ***2,782,500 gal.***

Volume of tank fills $= \frac{number\ of\ fills}{year} X\ Volume\ of\ tanks$

$$= \frac{50\ times}{year} X\ (650\ gal. + 500\ gal. + 500\ gal.)$$

$$= \mathbf{82{,}500\ gal.}$$

Volume of overflow = *overflow flow rate X time*

$$= \frac{7.5\ gal.}{min} X \frac{60\ min}{hour} X \frac{24\ hour}{day} X \frac{5\ days}{week} X\ 50\ weeks$$

$$= \mathbf{2{,}700{,}000\ gal.}$$

2b. Using the results from Question 1, calculate the volume of water used per part cleaned and the cost for cleaning each part. Assume that the cost for water including sewage is $2.25 per 1,000 gallons.

Volume of water,part) $= \frac{volume\ of\ water}{number\ of\ parts}$

$$= \frac{2782500\ gal.}{450000\ parts}$$

$$= \frac{\mathbf{6.18\ gallons}}{\mathbf{part}}$$

Total water costs = *Total volume of water X Water rate*

$$= 2{,}782{,}500\ gal.\ X \frac{\$2.25}{1000\ gal.}$$

$$= \mathbf{\$6260.63}$$

$$\frac{Cost\ of\ water}{part} = \frac{Volume\ of\ water}{part} X\ Water\ rate$$

$$= \frac{6.18\ gal.}{part} X \frac{\$2.25}{1000\ gal.}$$

$$= \frac{\mathbf{\$0.014}}{\mathbf{part}}$$

3. A detergent from Clean Brite is used in the wash tank at a initial concentration of 4% by volume. The detergent costs $20.00 per gallon. How much soap is required for each filling of the wash tank and at what cost? How much soap will be used in a year and at what cost? What will be the cost for the soap per part?

$$\frac{\text{Volume of soap}}{\text{filling}} = \text{Concentration soap X Volume of wash tank}$$
$$= 4\% \text{ X } 500 \text{ gal.}$$
$$= \frac{20 \text{ gal.}}{\text{filling}}$$

$$\frac{\text{Cost of soap}}{\text{filling}} = \frac{\text{Volume of soap}}{\text{filling}} \text{ X } \frac{\text{Cost of soap}}{\text{gallon}}$$
$$= \frac{20 \text{ gal.}}{\text{filling}} \text{ X } \frac{\$20.00}{\text{gallon}}$$
$$= \frac{\$400}{\text{filling}}$$

$$\frac{\text{Volume of soap}}{\text{year}} = \frac{\text{number of fillings}}{\text{year}} \text{ X } \frac{\text{volume of soap}}{\text{filling}}$$
$$= \frac{50 \text{ fillings}}{\text{year}} \text{ X } \frac{20 \text{ gal.}}{\text{filling}}$$
$$= \frac{1000 \text{ gal.}}{\text{year}}$$

$$\frac{\text{Cost of soap}}{\text{year}} = \frac{\text{Volume of soap}}{\text{year}} \text{ X } \frac{\text{Cost of soap}}{\text{gallon}}$$
$$= \frac{1000 \text{ gal.}}{\text{year}} \text{ X } \frac{\$20.00}{\text{gallon}}$$
$$= \frac{\$20000}{\text{year}}$$

$$\frac{\text{Cost of soap}}{\text{part}} = \frac{\text{cost of soap}}{\text{year}} \div \frac{\text{number of parts}}{\text{year}}$$
$$= \frac{\$20000}{\text{year}} \text{ X } \frac{\text{year}}{450000 \text{ parts}}$$
$$= \frac{\$0.044}{\text{year}}$$

4. What is the annual cost for water and chemicals when using the Clean Brite system? What is the cost per part?

$$\frac{\text{Total cost}}{\text{year}} = \frac{\text{total cost of water}}{\text{year}} + \frac{\text{total cost of chemicals}}{\text{year}}$$
$$= \frac{\$6260.63}{\text{year}} + \frac{\$20000}{\text{year}}$$
$$= \frac{\$26260.63}{\text{year}}$$

$$\frac{\text{Total cost}}{\text{part}} = \frac{\text{cost of water}}{\text{part}} + \frac{\text{cost of chemicals}}{\text{part}}$$
$$= \frac{\$0.014}{\text{part}} + \frac{\$0.044}{\text{part}}$$
$$= \frac{\$0.058}{\text{part}}$$

5. Squeaky Cleaners has heard about your project and they believe that they have a better detergent. Their detergent requires only four tank fills a year. The concentration of the detergent needs to be maintained at 2.00% by volume. Previous experience has shown that 250 parts can be washed with each gallon of this cleaner. The cleaner costs $7.00 per gallon. Compare the costs for the Squeaky Cleaner in terms of water, soap and total cost per part to the values calculated in Questions 3 and 4. Additionally, evaluate which cleaner would fulfill the goals of pollution prevention in terms of minimizing the amount of materials.

Volume of tank fills

$$= \frac{\text{number of fills}}{\text{year}} \times \text{volume of tanks}$$
$$= \frac{4 \text{ times}}{\text{year}} \times (650 + 500 + 500 \text{ gal.})$$
$$= \frac{6600 \text{ gal.}}{\text{year}}$$

Annual volume of overflow

$$= \text{flow rate of overflow} \times \text{year}$$
$$= \frac{7.5 \text{ gal.}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{24 \text{ hrs}}{\text{day}} \times \frac{5 \text{ days}}{\text{week}} \times \frac{50 \text{ weeks}}{\text{year}}$$
$$= \frac{2700000 \text{ gal.}}{\text{year}}$$

Total annual volume

$$= \text{volume of tank fills} + \text{volume of overflow}$$
$$= \frac{6600 \text{ gal.}}{\text{year}} + \frac{2700000 \text{ gal.}}{\text{year}}$$
$$= \frac{2706600 \text{ gal.}}{\text{year}}$$

Volume of water / part

$$= \frac{\text{total volume}}{\text{year}} \times \frac{\text{year}}{\text{part}}$$
$$= \frac{2706600 \text{ gal.}}{\text{year}} \times \frac{\text{year}}{450000 \text{ parts}}$$
$$= \frac{6.01 \text{ gal.}}{\text{parts}}$$

Total water costs / year

$$= \frac{\text{total volume of water}}{\text{year}} \times \text{water rate}$$
$$= \frac{2706600 \text{ gal.}}{\text{year}} \times \frac{\$2.25}{1000 \text{ gal.}}$$
$$= \frac{\$6089.85}{\text{year}}$$

Cost / part

$$= \frac{\text{volume of water}}{\text{part}} \times \text{water rate}$$
$$= \frac{\$6.01}{\text{part}} \times \frac{\$2.25}{1000 \text{ gal.}}$$
$$= \frac{\$0.014}{\text{part}}$$

Volume of soap required for each initial charge =
= percent soap X tank volume
= 2% X 500 gal.
= 10 gal.

Volume of soap required for 4 initial charges =
= number of charges X volume of soap per charge

$$= \frac{4 \text{ charges}}{\text{year}} X \frac{10 \text{ gal.}}{\text{charge}} = \frac{40 \text{ gal.}}{\text{year}}$$

Volume of soap to maintain 2%

$$= \frac{\text{number of parts}}{\text{year}} X \frac{\text{gal.}}{\text{part}}$$

$$= \frac{450000 \text{ parts}}{\text{year}} X \frac{\text{gal.}}{250 \text{ parts}}$$

$$= \frac{1800 \text{ gal.}}{\text{year}}$$

$$\frac{\text{Total volume of soap}}{\text{year}}$$ *= Volume of soap for initial charges + Volume of soap to maintain concentration*

$$= \frac{40 \text{ gal.}}{\text{year}} + \frac{1800 \text{ gal.}}{\text{year}}$$

$$= \frac{1840 \text{ gal.}}{\text{year}}$$

Annual cost of soap

$$= \frac{\text{Total volume of soap}}{\text{year}} X \frac{\text{cost of soap}}{\text{gal.}}$$

$$= \frac{1840 \text{ gal.}}{\text{year}} X \frac{\$7.00}{\text{gal.}}$$

$$= \frac{\$12800}{\text{year}}$$

$$\frac{\text{Cost of soap}}{\text{part}}$$ *= annual cost of soap / annual part production*

$$= \frac{\$12800}{\text{year}} X \frac{\text{years}}{450000 \text{ parts}}$$

$$= \frac{\$0.029}{\text{part}}$$

Total annual cost *= Annual cost of water + Annual cost of soap*

$$= \frac{\$6089.85}{\text{year}} + \frac{\$12800}{\text{year}}$$

$$= \frac{\$18889.85}{\text{year}}$$

Cost per part *= total annual cost / annual part production*

$$= \frac{\$18889.85}{\text{year}} X \frac{\text{year}}{450000 \text{ parts}}$$

$$= \frac{\$0.042}{\text{part}}$$

The Squeaky Chemical system should be used because of its lower cost and lower requirements for water and chemicals.

Production Unit

6. Congratulations! The pilot aqueous degreaser was such a success that corporate management has approved the purchase of a production unit. The unit will be capable of cleaning 2,100,000 parts per year. The tank sizes are:

Pre-wash tank	1,400 gal.
Wash	1,250 gal.
Rinse	1,300 gal.

The tanks will be drained and cleaned four times a year. The rinse tank overflows at 7.5 gpm. The finance department has asked you to estimate the volume of water and soap used per year. Additionally, they want the cost of the water and soap per year and the total cost per year. Use the soap concentration of the Squeaky Chemical system.

$$\text{Annual volume of tank fills} = \frac{\text{number of fills}}{\text{year}} \times \text{volume of tanks}$$
$$= \frac{4 \text{ times}}{\text{year}} \times (1400 + 1250 + 1300 \text{ gal.})$$
$$= \frac{\mathbf{15800 \text{ gal.}}}{\mathbf{year}}$$

$$\text{Annual volume of overflow} = \text{flow rate of overflow} \times \text{year}$$
$$= \frac{7.5 \text{ gal.}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{24 \text{ hrs}}{\text{day}} \times \frac{5 \text{ days}}{\text{week}} \times \frac{50 \text{ weeks}}{\text{year}}$$
$$= \frac{\mathbf{2700000 \text{ gal.}}}{\mathbf{year}}$$

$$\text{Total annual volume of water} = \text{volume of tank fills} + \text{volume of overflow}$$
$$= \frac{15800 \text{ gal.}}{\text{year}} + \frac{2700000 \text{ gal.}}{\text{year}}$$
$$= \frac{\mathbf{2715800 \text{ gal.}}}{\mathbf{year}}$$

$$\frac{\text{Total water costs}}{\text{year}} = \frac{\text{total volume of water}}{\text{year}} \times \text{water rate}$$
$$= \frac{2715800 \text{ gal.}}{\text{year}} \times \frac{\$2.25}{1000 \text{ gal.}}$$
$$= \frac{\mathbf{\$6110.55}}{\mathbf{year}}$$

Volume of soap required for each initial charge =
= percent soap X tank volume
= 2% X 1250 gal.
= 25 gal.

Volume of soap required for 4 initial charges =
= number of charges X volume of soap per charge

$$= \frac{4 \text{ charges}}{\text{year}} \times \frac{25 \text{ gal.}}{\text{charge}}$$
$$= \frac{\mathbf{100 \text{ gal.}}}{\mathbf{year}}$$

$$\text{Volume of soap to maintain 2\%} = \frac{\text{number of parts}}{\text{year}} \times \frac{\text{gal.}}{\text{part}}$$
$$= \frac{2100000 \text{ parts}}{\text{year}} \times \frac{\text{gal.}}{250 \text{ parts}}$$
$$= \frac{8400 \text{ gal.}}{\text{year}}$$

$$\frac{\text{Total volume of soap}}{\text{year}} = \text{Volume of soap for initial charges} + \text{Volume of soap to maintain concentration}$$
$$= \frac{100 \text{ gal.}}{\text{year}} + \frac{8400 \text{ gal.}}{\text{year}}$$
$$= \frac{8500 \text{ gal.}}{\text{year}}$$

$$\text{Annual cost of soap} = \frac{\text{Total volume of soap}}{\text{year}} \times \frac{\text{cost of soap}}{\text{gal.}}$$
$$= \frac{8500 \text{ gal.}}{\text{year}} \times \frac{\$7.00}{\text{gal.}}$$
$$= \frac{\$59500}{\text{year}}$$

$$\text{Total annual cost} = \text{Annual cost of water} + \text{Annual cost of soap}$$
$$= \frac{\$6110.55}{\text{year}} + \frac{\$59500}{\text{year}}$$
$$= \frac{\$65610.55}{\text{year}}$$

7. Compare the unit production costs for the water, the soap, and the total with the values for the pilot unit using Squeaky Chemical's soap. Comment on any trends.

Pilot unit

$$\text{Unit cost of water} = \frac{\$0.014}{\text{part}}$$
$$\text{Unit cost of soap} = \frac{\$0.029}{\text{part}}$$
$$\text{Total unit cost} = \frac{\$0.042}{\text{part}}$$

Production Unit

$$\text{Unit cost of water} = \frac{\text{cost of water}}{\text{year}} / \text{production rate}$$
$$= \frac{\$6110.55}{\text{year}} \times \frac{\text{year}}{2100000 \text{ parts}}$$
$$= \frac{\$0.003}{\text{part}}$$

$$\text{Unit cost of soap} = \frac{\text{cost of soap}}{\text{year}} / \text{production rate}$$
$$= \frac{\$59500}{\text{year}} \times \frac{\text{year}}{2100000 \text{ parts}}$$
$$= \frac{\$0.028}{\text{part}}$$

$$\text{Total unit cost,} = \frac{\text{total cost}}{\text{year}} / \text{production rate}$$
$$= \frac{\$65610.55}{\text{year}} \times \frac{\text{year}}{2100000 \text{ parts}}$$
$$= \frac{\$0.031}{\text{part}}$$

All these costs decrease because the initial charges of chemicals are spread over more processed parts.

8. The toxicology department uses an analytical system called the toxicology index to rate the toxicity of chemicals in the environment. The system involves multiplying the total quantity of a substance used in the process by a weighting factor for that particular substance. Compare the toxicology index of the aqueous production process with a TCE unit of the same capacity. What does the toxicology index indicate about pollution prevention?

The density of water is 8.3 lbs. per gallon and of the soap is 8.0 lbs. per gallon. The TCE production unit uses 1.8 X 10^6 lbs. of TCE annually. The toxicology numbers are:

Substance	Weighting factor (lbs.$^{-1}$)
TCE	16
water	1
soap	1.2

Note: The weighting factors were developed only for this problem set. In consulting practice, toxicity evaluations are considerably more complicated.

TCE Unit $= \text{Tox Number} \times \text{Wt. of TCE}$

$= 16 \text{ lbs.}^{-1} \times 1.8 \times 10^6 \text{ lbs.}$

$= \mathbf{2.88 \times 10^7}$

Aqueous Unit $= \text{Tox Number of Water} \times \text{Wt of Water}$

$+ \text{Tox Number of Soap} \times \text{Wt of Soap}$

$= 1 \text{ lbs.}^{-1} \times 2715800 \text{ gal} \times \frac{8.3 \text{lbs.}}{\text{gal.}} + 1.2 \text{lbs.}^{-1} \times 8500 \text{ gal} \times \frac{8 \text{ lbs.}}{\text{gal.}}$

$= \mathbf{2.26 \times 10^7}$

$$\text{Percent Difference} = \frac{\text{TCE Unit}}{\text{aqueous unit}}$$

$$= \frac{2.88 \times 10^7}{2.05 \times 10^7}$$

$$= 127\ \%$$

One can see that even though the aqueous process produces more waste, the difference in toxicity more than compensates. Therefore, it is possible to make a process change which both results in cost savings and reduces environmental impacts.

National Pollution Prevention Center
for Higher Education

Doc # 93-1
April 1993

CASE STUDY

Corporate Strategy
Operations Management

Agent Regeneration and Hazardous Waste Minimization

The IBM Corporation
Endicott, New York Facility

L. Richard Oliker, School of Management, Syracuse University

Donald Powell, IBM Endicott

Jack Lubert, IBM Endicott

Dennis Whittaker, IBM Endicott

INTRODUCTION

International Business Machines Corporation (IBM) was given its initial impetus by Thomas J. Watson, Sr. in Endicott, New York. In 1915, as the new president of the Computing-Tabulating-Recording Company, his concepts for business success marked the beginning of the firm's growth. He changed the company's name to IBM in 1924, as a reflection of the growth achieved up to that time.

IBM's growth was sustained and continuous from that period on. The excellence of its accounting machines was responsible for its success up to the start of World War II, which brought about a product change from business machines to ordnance. In 1946, IBM helped to initiate the age of electronics through the introduction of its first commercial electronic computer. Today, the company is primarily a manufacturer and marketer of a full range of computing information equipment and software, with sales revenues in 1991 of approximately $65 billion.

IBM is now aggressively working toward improving both its competitiveness and efficiency. Work force reductions have been accelerated to reduce operating expenses. The general product line has been strengthened, and a series of strategic alliances have been announced with firms

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such as Apple Computing, Motorola, Siemens, etc. In addition, IBM continues to build upon its position as an industry leader in the areas of research, development, and engineering.

These changes were made in recognition of the fact that the information technology industry is currently undergoing a fundamental transition. This transition is "characterized by rapid technological advances, shorter product life cycles, growth of software and services, and increasing competition. As a result, IBM will change from a single, vertically integrated, very complex worldwide enterprise to one of increasingly autonomous businesses. Each business, empowered with varying degrees of independence, will be focused and responsible to its markets." (IBM 1991 Annual Report, p. 35)

THE REGULATORY ENVIRONMENT

The Pollution Prevention Act of 1990 establishes pollution prevention as a national objective. The Act notes that:

> There are significant opportunities for industry to reduce or prevent pollution at the source through cost-effective changes in production, operation, and raw materials use. The opportunities for source reduction are often not realized because existing regulations, and the industrial resources they require for compliance, focus upon treatment and disposal, rather than source reduction. . . . Source reduction is fundamentally different and more desirable than waste management and pollution control.

Manufacturing firms are impacted by the above Act as well as other federal environmental laws, such as the Resource Conservation and Recovery Act, Toxic Substances Control Act, the Clean Air Act, and the Clean Water Act.

Because of increasing demands by this complex regulatory system, which includes state and local laws as well, the cost to U.S. industry is escalating rapidly. The projected annual cost of compliance with hazardous waste controls alone is expected to exceed $12 billion by the end of this decade. This will be double the amount spent for such compliance in 1991. Cleaning up hazardous waste sites will add another $8 billion annually by 1999; with an added $5 billion needed to clean up leaking underground chemical/petroleum storage sites.

Expanded coverage of existing laws on National Ambient Air Quality Standards and toxic air emissions will likely hasten the renovation of some manufacturing facilities. However, many older plants are likely to close, as their revenue production potential falls below the cost of clean-up.

Environmental Engineering Case Study Problem Set

1. How many parts can be processed in a year with the pilot unit if it averages 75 parts per hour? Assume production 50 weeks a year, 5 days a week and 24 hours a day.

Pilot Unit

2a. Calculate the total volume of water used by the pilot unit in one year. The tanks sizes are:

Pre-wash tank	650 gal.
Wash	500 gal.
Rinse	500 gal.

The tanks have to be drained and cleaned once a week. The rinse tank overflows at 7.5 gpm. Assume no evaporative loses.

2b. Using the results from Question 1, calculate the volume of water used per part cleaned and the cost for cleaning each part. Assume that the cost for water including sewage is $2.25 per 1,000 gallons.

3. A detergent from Clean Brite is used in the wash tank at a initial concentration of 4% by volume. The detergent costs $20.00 per gallon. How much soap is required for each filling of the wash tank and at what cost? How much soap will be used in a year and at what cost? What will be the cost for the soap per part?

4. What is the annual cost for water and chemicals when using the Clean Brite system? What is the cost per part?

5. Squeaky Cleaners has heard about your project and they believe that they have a better detergent. Their detergent requires only four tank fills a year. The concentration of the detergent needs to be maintained at 2.00% by volume. Previous experience has shown that 250 parts can be washed with each gallon of this cleaner. The cleaner costs $7.00 per gallon. Compare the costs for the Squeaky Cleaner in terms of water, soap and total cost per part to the values calculated in Questions 3 and 4. Additionally, evaluate which cleaner would fulfill the goals of pollution prevention in terms of minimizing the amount of materials.

Production Unit

6. Congratulations! The pilot aqueous degreaser was such a success that corporate management has approved the purchase of a production unit. The unit will be capable of cleaning 2,100,000 parts per year. The tank sizes are:

Pre-wash tank	1,400 gal.
Wash	1,250 gal.
Rinse	1,300 gal.

The tanks will be drained and cleaned four times a year. The rinse tank overflows at 7.5 gpm. The finance department has asked you to estimate the volume of water and soap used per year. Additionally, they want the cost of the water and soap per year and the total cost per year. Use the soap concentration of the Squeaky Chemical system.

7. Compare the unit production costs for the water, the soap, and the total with the values for the pilot unit using Squeaky Chemical's soap. Comment on any trends.

8. The toxicology department uses an analytical system called the toxicology index to rate the toxicity of chemicals in the environment. The system involves multiplying the total quantity of a substance used in the process by a weighting factor for that particular substance. Compare the toxicology index of the aqueous production process with a TCE unit of the same capacity. What does the toxicology index indicate about pollution prevention?

The density of water is 8.3 lbs. per gallon and the soap is 8.0 lbs. per gallon. The TCE production unit uses 1.8×10^6 lbs. of TCE annually. The toxicology numbers are:

Substance	**Weighting factor (lbs.$^{-1}$)**
TCE	16
water	1
soap	1.2

Note: The weighting factors were developed only for this problem set. In consulting practice, toxicity evaluations are considerably more complicated.

In this case, the specific Environmental Protection Agency Regulation for Solid Waste, 40 CFR 258, "Criteria for Municipal Solid Waste Landfills" applied and could not be met, given the amount of chromium contained in the waste sludge produced by the problem manufacturing process (to be described in detail in the next section of this case). A more definitive and limiting part of the regulations is 40 CFR 261, "Regulation for Identifying Hazardous Wastes." Again, the waste sludge failed to pass the test because of excessive chromium leaching potential.

The effective managerial approach for the future to all of this new legislation calls for a new approach. Manufacturers can no longer wait to see what new regulatory requirements will demand. In order to survive in the changing environmental dynamic of the rest of this decade, they will have to become much more proactive. This new strategy will call for an alliance between manufacturers, regulators, and environmentalists. As is the lesson provided in this case, other firms will have to learn that waste minimization can be environmentally as well as competitively sound.

PROBLEM IDENTIFICATION

In the evolution of this case and as a matter of stated corporate policy, IBM is fully committed to the minimization of the environmental impact from all of its various manufacturing operations. Hazardous waste reduction programs are in place throughout the firm to:

1. Effect waste reduction at the source.
2. Encourage recycling.
3. Develop and implement waste treatment technologies.

IBM's Endicott, New York facility has expanded its operations to include science centers, research laboratories, product development activities, and manufacturing. It currently employs approximately 8,500 people and its primary mission is to:

1. Develop and manufacture technology packaging.
2. Develop systems software.
3. Manufacture bank systems.

Composed of five million square feet of floor space, Endicott is one of IBM's largest plant-lab sites. Its product line consists of a variety of computer processors, banking systems, circuit packaging, and printers. It is this latter product series which serves as the focus of the case. More specifically, a component part—printbands—of most of the impact printers manufactured at this location.

Impact printers have over two hundred component parts. Printbands are stainless steel belts which are used in most such printers. Panels of raw stainless steel, measuring one foot by five feet by 1/2 the thickness of a dime, from which ten printbands can be produced, are used in the basic manufacturing process described below. The resultant printbands are approximately 3/4 of an inch wide with raised characters for printing. The character sets on the bands are subject to change, based upon specific customer requirements.

The manufacturing process used to produce printbands at the Endicott facility involves a photolithographic process in which the stainless steel panels are chemically machined using a strong ferric chloride etching solution containing hydrochloric acid. The waste material which results from this chemical reaction is a solution composed primarily of ferrous chloride.

The chemical process which takes place involves an oxidation/reduction reaction in which the iron (Fe^{+3}) ions are reduced, while iron (Fe) is oxidized. The net product of this reaction is the formation of, or dissolution of iron in the solution in the form of iron ions in the +2 oxidation state, called ferrous ions (Fe^{+2}). This reaction may be chemically represented as:

$$\overset{0}{Fe} + 2\,\overset{+3}{Fe}Cl_3 = 3\,\overset{+2}{Fe}Cl_2$$

Stainless Steel	Etchant	Dissolved Steel Spent Etchant

Typically, approximately 50,000 printbands are manufactured annually through this process at the Endicott plant. In 1986, this chemical process consumed 158,300 gallons of ferric chloride etching agent, and generated 1,890 tons of hazardous waste sludge, along with 34,200 gallons of concentrated waste etchant which was trucked off site for treatment prior to its disposal in a landfill.

For each printband panel, up to that period, 1.48 pounds of material had to be etched away from the surface to form the final product. This waste material included 1.24 pounds of iron, .2

pounds of chromium, and .04 pounds of molybdenum. On the average, 32 gallons of the ferric chloride solution were required for the etching of one print band panel. This solution weighed 400.5 pounds, including 60.3 pounds of iron.

The manufacturing process was a batch operation. Etching machines were filled with fresh etchant solution once a shift. The etchant was heated to 130 degrees F, 15 pints of hydrochloric acid was added, and the etchant was balanced by the addition of water. The operator started the printband panels through the machine and, because the etching solution was new, the bath's oxidation-reduction potential (ORP) was high. Thus, the etch rate was swift for the first group of panels to be etched.

As additional panels entered the solution, the bath lost some of its etching power as the chemical reaction took place. The operator had to keep adjusting the conveyor speed to compensate for this decrease in etching power. After 12 to 14 panels had been etched, the conveyor speed would have dropped to less than half of the original starting speed. Thus, the efficiency of the process was dependent, in large part, on the skill of the operator to make a high quality product in an environment of constantly changing etching parameters.

At the end of each of the three daily work shifts, the etching solution bath was dumped, the solution-spray nozzles were removed, the etched machine sump was cleaned, clean nozzles were installed, fresh etchant added, and the bath heated up for the next shift. This set-up operation required about two hours per shift to complete, making it a fairly expensive operation in terms of both downtime and labor.

The spent etching solution, plus the waste flow from the panel rinsing operations, was dumped into the site waste collection system for treatment. This waste was pumped to the facility's waste treatment plant where the soluble iron ions were converted to a precipitate by combination with hydroxide ions, the usual practice used in treating heavy metal wastes. This treatment resulted in clean water, which could be safely discharged, and a sludge which was hauled away from the plant in large containers by a vendor and disposed in a landfill at some considerable expense. At that time, the plant shipped its waste to a specific location in Quebec, where it was formulated into a non-leachable, stabilized matrix prior to burial.

The waste etch solution contained a large quantity of hydrochloric acid, which made its extremely corrosive. This acid was neutralized via the addition of a hydrated lime slurry solution. All

(99.9%) of the metals end up in the precipitate. As noted, the chemical composition of the sludge is ferrous chloride. It also includes a residual of the chromium deposits contained in the stainless steel, which was etched away in the chemical reaction. This metal is the component which classified the sludge as "hazardous" and added to its disposal cost.

During the second quarter of 1986, the production of 80 printband panels per day created excessive demands on the waste treatment plant equipment. The sludge processing equipment simply could not keep up with the waste etchant output. As an expedient alternative, the etchant which could not be processed on site was hauled in tank trucks to outside vendors for treatment. About ten large tank trucks of such material were removed from the plant that year—again, at considerable expense.

Environmental engineers at the Endicott plant were aware at the time that ferric chloride solutions had a market that was readily available. At many sewage treatment plants in the region, such a solution is injected into the treatment process as an aid to accelerate flocculation. They pursued this alternative option as an attractive means of disposal. Unfortunately, the chromium content of the solution caused it to be unacceptable for any alternative use application.

As noted, the above manufacturing/treatment/disposal process was utilized in 1986 and for at least 15 prior years. Demand projections for printbands from 1986 to 1991 showed a sharp increase. Such an increase would normally require either:

1. Additional sludge handling equipment to be installed at the plant's waste treatment site; or
2. An increase in off-site waste treatment/disposal dependency. (1991 printband production plan volumes would necessitate a 300% increase.)

In late 1986, this complex problem situation was brought to a head. A chemical outage occurred on the ferric chloride supply system which resulted in a printband production shut-down for several days. This shut-down occurred at a time when some critical printband orders were being processed. This shortage served to heighten management's sensitivity to the chemical supply/waste generation problem associated with this manufacturing process.

Management's response to the above critical situation was to immediately appoint a task

force to directly address this problem. The task force was charged to:

1. Ensure adequate virgin ferric chloride storage capacity to prevent manufacturing interruptions.
2. Increase the conservation practices of ferric chloride in the manufacturing cycle.
3. Enlist engineering groups throughout the company to invent a process to *regenerate* the ferric chloride solution used to manufacture printbands (in line with the basic IBM site strategy of waste minimization).

STRATEGIC ALTERNATIVES

Since the volume of ferric chloride etchant was so great, and the waste formed in the printband manufacturing process was so voluminous, the incentive to investigate the various methods of effecting ferric chloride etchant regeneration was considered to be not only justifiable, but imperative.

All chemical reactions are reversible. However, the ease and cost of reversibility varies widely, depending upon the chemicals involved. In the case of the ferric chloride etching solution, it was recognized that various methods existed which could be utilized to reverse the chemical process and reform the iron (Fe^{+3}) ions from the spent etchant. However, it was also clearly understood that regeneration of the etchant was the *only* alternative which could result in a significant reduction in the volumes of etchant used in the manufacturing process and the waste created by that same process.

Inherent in all of the regeneration processes examined up to that time was the use of extremely reactive, hazardous, and toxic chemicals, or electrical energies which were extremely high. Chemicals such as chlorine gas, hydrogen peroxide, sodium chlorate, and other strong oxidants were often employed. Although effective in regenerating ferric chloride etchant, personnel safety would almost certainly be at risk when chemicals of this nature were employed.

Rather than place its employees in a hazardous manufacturing environment which employed such strong chemicals (specifically, the three cited in the above paragraph), IBM scientists and engineers decided to investigate three strategic, problem-solving alternatives:

1. Creation of an electrochemical process of regeneration via as yet undeveloped equipment.
2. The injection of ozone gas into the ferric chloride solution during the manufacturing process.
3. The use of air oxidation as the regeneration agent.

A. The Electrochemical Option

This option was initiated at the behest of the Environmental Engineering Department at the IBM Endicott plant. The management of Printband Manufacturing was provided an in-depth briefing of the significant impact of their etching process on the site's waste treatment systems. In order to show good faith in addressing this concern, Printband Manufacturing management sponsored and funded the electrolytic process as part of the Endicott Technical Development (ETD) organization's annual budget for development projects.

A high-ranking member of the ETD organization had prior experience with an electrolytic process, and he assigned the investigation of this option to an employee with whom he shared the responsibility for its development. An aggressive approach was taken, which projected enormous waste volume reductions. Progress was presented in highly technical terms at monthly development status meetings.

In presenting the results of this option, many negative references were made to the Ozone option—which was not being developed at the Endicott plant and, as a result, *not* represented at these meetings. When rebuttals of arguments against the Ozone option were presented, Endicott ETD management countered that the sort of competition presented by this (the Ozone) option was not beneficial to the Electrolytic option and should not be pursued. Consequently, only viable test results were reported at these meetings, with development project assessors being led to believe that *every* test was successful.

B. The Ozone Gas Option

Like the Electrolytic Option, the Ozone approach to agent regeneration was sponsored by Printband Manufacturing management. It was initiated via a paper presented at an IBM technology-based meeting, authored by a development chemist at the East Fishkill, New York, plant. His

etchant regeneration system was in the process of being implemented at that location after months of testing and approvals. Like the Endicott plant, the Fishkill process involved a ferric etchant.

Printband Manufacturing management only became aware of the proposed Ozone regeneration system *after* they had already authorized the Endicott Technology Development organization to investigate the Electrolytic option. ETD had already been provided the funding for its activities and no funds were available to support the Ozone option development efforts without a considerable loss of "face."

The Ozone option development team at the East Fishkill location wanted very badly to sell its system elsewhere, and so had agreed to do the development testing at no cost to Printband Manufacturing management. Some minimally valued equipment was made available to the Ozone process developers and it was refurbished for use at that location.

Infrequent trips were made to visit the Ozone project by Printband Manufacturing engineering personnel for feasibility and review purposes. Two or three development status memorandums were weekly transmitted to the Endicott facility. All testing and results continued to be favorable. No unsuccessful test results, of which there were a number, were ever reported directly to Endicott, nor was the development chemist free to travel to that location to directly report progress and status.

C. The Air Oxidation Option

Early in 1987, two Printband Manufacturing engineers and an Environmental Engineering acquaintance began work at the Endicott facility on an idea being used in the copper etching process areas in the plant. They investigated the injection of compressed air into the piping loop through which the etchant was circulated during etching. This method worked with some degree of success with cupric chloride etch systems, but chemical thermodynamics did not appear to favor a similar promise for ferric chloride.

Etchant conservation practices were immediately implemented to:

1. Monitor the etchant bath thru-put to better define bath life and ensure complete bath exhaustion prior to dumping to the treatment/disposal process.
2. Modify a preliminary step in printband manufacturing called "flash etch" to decrease ferric chloride consumption.

However, with a minimal investment of both time and capital, the engineers were authorized by Printband Manufacturing management to set up a pilot test system using compressed air on one of three ferric chloride etchers in the manufacturing area. The net result of the preliminary tests for this simple $12,000 system was a repeatable 17% decrease in the volume of the etchant required in the etch process. Most of the components of this air oxidation system were either used, donated from inactive systems, or fabricated on site to expedite installation.

These six month test results and the consequent savings were significant enough to warrant implementation of similar systems on two new etchers being installed at that time (at a total cost for all etchers of less than $50,000). This investment was readily recouped through chemical and waste volume reductions. The return was over 130%, and the payback period was achieved in about *nine* months. As a result, no further off-site treatment of the ferric chloride waste would be necessary.

Additionally, planned follow-up testing, employing oxygen enriched air and pure oxygen, was conducted in 1988. The net result of the oxygen testing was a system which would regenerate etchant at a rate which matched normal production requirements. Etchant regeneration could now be carried out in a working etcher at such a rate that no fresh etchant was required to maintain the etch rate. The printband panel conveyor could be set at a standard speed, thus reducing operator time and expense, and simplifying the etching process.

These tests came at a very critical moment. An equipment problem on the bulk ferric chloride system made it impossible to pump virgin etchant from either of the two 5,000 gallon bulk supply tanks to the etchers. This would have shut down production for several days had it not been for the (then) pilot oxygen regeneration system in place. Manufacturing continued on an uninterrupted basis during the period when this pumping failure was being corrected.

These test results were presented to management and capital funds were made available to enhance and upgrade the initial air-oxidizing systems to the more effective oxygen systems. Oxygen generators were installed and the regeneration of ferric chloride etchant was fully operational in October of 1989, three months ahead of schedule. Further testing was being conducted on this process at the very same time that the Ozone and Electrolytic options were still being developed. Additionally, a patent application was filed and remains active today.

No toxic or hazardous chemicals were employed, no exotic, sophisticated equipment

requiring a trained staff of maintenance personnel was necessary, and operational costs were minimal.

ALTERNATIVE TECHNOLOGY COMPARISON

Technology	Pros	Cons
Ozone	Fast reaction Complete regeneration Developed at IBM Being pilot tested Reaction by-product is water Process in multiple use applications	Highly reactive Toxic as by-product Filtration may be required Cost estimate set at $650,000
Electrolytic	Proven feasibility in labs Complete regeneration Developed at IBM	No full-scale operating system Labor intensive High electrical cost and usage High voltage hazard Cost estimated at $650,000 (Plus)
Oxygen	Proven feasibility Developed at IBM Filtration not required Minimal labor involved Low operating costs Easy installation Actual cost-$150,000	Slow reaction No successful operations* Potential for full regeneration not known* IBM would be first application

*Situation at the initiation of the testing of this option.

THE DECISION PROCESS

The Oxygen Option was ultimately approved on economic grounds. Since it was not developed by the Endicott Technical Development organization, some of the ties to that unit were severed as a result of this decision.

The "winning" system was easily implemented by making simple hookups to replace plant compressed air with oxygen generators. While some bugs had yet to be fully worked out of the system, Printband Manufacturing management was satisfied with its overall effectiveness. The approval for purchase, installation and testing of the full system was *not* shared with the Ozone and the Electrolytic development teams at the time the "go-ahead" decision was made—on the grounds that the "politics" were not right.

The air oxidation option was a unique method of ferric chloride regeneration, developed and implemented utilizing a simple combination of readily available hardware and a non-toxic gas (Oxygen). The final return on investment (ROI) was over 185%, with a four month payback period. The entire system was actually paid for in the savings associated with virgin chemical and waste costs experienced during the engineering pilot testing periods for this project. Because of the reduced virgin ferric chloride demand, the additional bulk holding capacity was never required. Additionally, this system is now being installed to replace regeneration methods on other etch systems at the Endicott plant.

This new regeneration system requires minimal maintenance and repair activity, as well as very infrequent operator attention. The cost savings and environmental benefits, in terms of reduced volumes of solid, hazardous waste for landfilling, continue with every printband produced today.

CONCLUSIONS

In 1991, only 4,122 gallons of ferric chloride etchant were consumed in the printband manufacturing process. This resulted in only 78 tons of hazardous waste sludge shipped to a landfill. This represented a production normalized reduction of 94.2% in etchant use and a 90.8% reduction in the hazardous waste generated by this manufacturing process.

A total system to support the oxygen regeneration option for all printband manufacturing etchers could be purchased and installed for less than one quarter the cost of either the ozone or the electrochemical alternative methods still in the development stage. The inherent risks to personnel associated with those two options were thus avoided.

It is understood that without management's commitment to continuing development efforts, a project such as this would never have realized its full potential. It is the never-ending quest to continually improve on existing processes that can sometimes lead to dramatic advancements, as evidenced in the case presented.

Waste minimization at IBM Endicott is not a targeted activity that is done on a periodic basis. Rather, it is the daily activity for many of the engineering and manufacturing personnel on that site, and at all other IBM manufacturing facilities. New waste minimization opportunities are identified and tracked at high levels of management. It is this constant focus that has aided IBM to significantly reduce its waste volumes in the past few years.

FEASIBILITY ANALYSIS

Hudson Ice Cream Answer Sheet

OPTION			
CAPITAL COSTS			
Equipment purchase			
Installation & start-up			
Total Capital Costs			
			Incremental
OPERATING CASH FLOWS	**Current Costs**	**Option Costs**	**(Costs) & Savings**
Raw materials			
Production & maintenance labor			
Utilities			
> Water			
> Electricity			
> Gas/Oil			
Waste Management			
> Labor			
> Chemicals			
> Testing/Monitoring			
> Disposal			
> Labeling/Manifesting			
> Recording/Filing			
Regulatory fees (TURA)			
Regulatory fines			
Dealing with regulatory staff			
Total Annual Operating Cash Flows			
BEFORE -TAX CALCULATION			
Incremental cash flows			
x PV Annuity Factor (10 yrs @ 20%)			
= Before Tax PV			
- Total capital costs			
= Before Tax Net Present Value			
AFTER -TAX CALCULATION			
Incremental cash flows			
- Depreciation			
= Taxable Income			
Income Tax @ 40%			
Incremental cash flows			
- Income Tax			
= After tax cash flow			
x PV Annuity Factor (10 yrs @ 12%)			
= After tax Present Value			
- Total capital costs			
= After Tax Net Present Value			

ARTICLES

INTRODUCTION TO POLLUTION PREVENTION

UNK

8

Developing and Maintaining a Pollution Prevention Program

Laurie Case

Laura Mendicino

David Thomas

Illinois Hazardous Waste Research and Information Center
Champaign, Illinois

Industrial waste generation in the United States averages billions of pounds daily. Discharged to our air, water, or land, this waste represents a significant loss of raw materials and a potential threat to human health and the environment. To be responsible guardians of environmental quality, waste generators must review their production processes and business operations as well as consider the economic and the environmental benefits of implementing a pollution prevention program.

Due to increasing environmental concerns associated with industrial waste, companies must now incorporate waste management and prevention strategies into their industrial processes. Adopting a pollution prevention program as a way of doing business can provide a number of significant benefits to a company. Figure 8-1 provides a brief overview of what pollution prevention means,

Source: Freeman, Harry; Industrial Pollution Prevention Handbook

What

Pollution prevention—any in-plant practice that reduces or eliminates the amount and/or toxicity of pollutants which would have entered any wastestream or would otherwise have been released into the environment prior to management techniques such as recycling, treatment, or disposal. Pollution prevention includes the design of products and processes that will lead to less waste being produced by the manufacturer or the end user.

Who

Any business that

- Generates waste
- Uses hazardous materials
- Emits or discharges waste into the air, water, or land
- Wants to save money through reducing waste-handling costs, raw material costs, and production costs
- Wants to operate in an environmentally sound and responsible manner

Why

Businesses that implement a pollution prevention program

- Avoid rising costs of waste disposal
- Save money in other areas such as purchasing of raw materials
- Increase their industrial efficiency
- Maintain or increase competitiveness
- Decrease long-term liability
- Follow state and federal policy guidelines
- May reduce present and future regulatory burdens
- Improve environmental and workplace conditions
- Ensure community safety
- Maintain good corporate image

Figure 8-1. An introduction to pollution prevention.

who should be considering developing a pollution prevention program, and why it is important.

By decreasing the amount of waste generated or released, a company can reduce waste disposal costs, improve worker safety, and reduce long-term liability. In addition, pollution prevention methods should lead to increased efficiency of the production line and decreased costs associated with the purchase of raw materials, inventory control, and so forth. Any resulting changes in effi-

ciency or expenditures may help the company to maintain or improve its competitiveness in the marketplace.

A pollution prevention program develops from a thorough understanding of the facility from both a production and human resources standpoint. This knowledge, combined with commitment to implement pollution prevention techniques or technologies, can help a company meet, exceed, or even eliminate its regulatory responsibilities.

This chapter focuses on the establishment of a pollution prevention program, and methods to sustain such a program once in place. Other steps needed to implement a pollution prevention program are discussed only briefly, as many are covered elsewhere in this handbook or in the publications listed at the end of this chapter. There is no simple formula that every company can follow to establish a program; however, there are some basic steps every company should examine and undertake in developing its unique approach to pollution prevention.

8.1 Benefits of and Obstacles to a Pollution Prevention Program

Pollution prevention can be viewed as business planning with environmental benefits. The most common benefits of and incentives for establishing a pollution prevention program are presented in Table 8-1. Some of the obstacles that may hinder implementation or program development are presented in Table 8-2.

Table 8-1. Incentives for Pollution Prevention

Reduced operating cost	Money will be saved in the long term.
	Many projects have good return on investment and short payback period.
	Savings in disposal and raw materials costs reduce overall operating costs.
Improved worker safety	Reducing toxics improves working environment and decreases personal protective requirements.
Reduced compliance costs	Pollution prevention projects can reduce regulatory exposure.
	Some projects may eliminate need for permits, manifesting, monitoring, and reporting, saving time and money.
Increased productivity	Pollution prevention can result in more efficient use of raw materials due to improved processes and operations.
Increased environmental protection	Pollution prevention reduces waste generation, assuring improved long-term environmental protection and reduced future liability costs.
Continuous improvement	Pollution prevention can be an integral part of a company's TQM or continuous improvement program.

Table 8-2. Obstacles to Pollution Prevention

Capital requirements	Projects may require capital investments.
Specifications	Production materials may be toxic and/or hazardous and could be replaced with more environmentally sound alternatives, but contracts may specify that the toxic compounds be used.
Regulatory issues	New or modified permits may be necessary.
Product quality issues	Pollution prevention projects may change product quality.
Customer acceptance	Anything that affects quality or perceptions of quality may affect customer acceptance.
Immediate production concerns	Companies are often hesitant to admit that the "old way" may not have been the best way.
Available time and technical expertise	Time or sufficient expertise may be lacking.
Inertia	The "If it ain't broke, don't fix it" attitude may prevail.

8.2 Definition of Pollution Prevention Program, Plan, and Project

There is considerable confusion about the meanings of the terms *pollution prevention program, plan,* and *project*. Many companies have compiled a list of projects and called the list a plan—such a list is not a plan. Creating a *pollution prevention program* involves developing and implementing a continuous strategy to reduce all waste generated by a facility, in addition to procedures for prioritizing and systematically reducing these wastes. A *pollution prevention plan* is a written guide to how the program will be implemented and is used to chart the progress of the program. It reiterates management support, lists reasons for the program, identifies the pollution prevention team, describes how waste will be characterized, provides a strategy and schedule for pollution prevention assessments, institutes a cost allocation system, indicates how technology transfer will take place, addresses training needs, and discusses how the program and projects will be evaluated and implemented. The plan must be updated periodically to reflect the continuous nature of a pollution prevention program. *Projects* are the specific activities undertaken to reduce or eliminate waste.

8.3 Overview of Steps to Implementing a Pollution Prevention Program

Many companies initiate only portions of a pollution prevention program, undertaking some specific projects, but then finding it difficult to maintain

momentum. Often this is because there is not full commitment to a program Unless pollution prevention is integrated into the company's business practices, early successes with pollution prevention projects may not be enough to sustain the program. By developing a program based on the following steps, a company can build and maintain a vigorous pollution prevention program. The concepts presented are applicable to the reduction of all waste regardless of medium, quantity, or toxicity. Suggestions are targeted at middle-management personnel. To apply these suggestions, each industry or facility will need to interpret them so they are made specific for their situation.

A manual developed by the Illinois Hazardous Waste Research and Information Center (HWRIC), *Pollution Prevention: A Guide to Program Implementation* (Illinois Hazardous Waste Research and Information Center, 1992), details each of the eight steps (see Fig. 8-2). The steps to establish and maintain a pollution prevention program are:

1. Obtain support from top management.
2. Get the program started by beginning to incorporate changes throughout the company, developing a written pollution prevention plan, and training employees in pollution prevention.
3. Review and describe in detail the manufacturing processes within the facility to determine the raw materials used and the sources of waste generation and to define a baseline inventory to be used to set goals and evaluate progress.
4. Identify potential pollution prevention opportunities for the facility.
5. Determine cost of current waste generation and establish a system of proportional waste management charges for those departments that generate waste.
6. Select the best pollution prevention options for the company and implement these choices.
7. Evaluate the pollution prevention program on a companywide basis, as well as evaluating specific pollution prevention projects.
8. Maintain and sustain the pollution prevention program for continued growth and benefits to the company. Reevaluate the program as economic situations change and/or process equipment requires upgrading.

This chapter will specifically examine steps 1, 2, and 8. Other chapters should be examined for in-depth information on the other topic areas.

8.4 Top-Management Support

Management commitment to the philosophy and the long-term process of implementing and maintaining a pollution prevention program provides the

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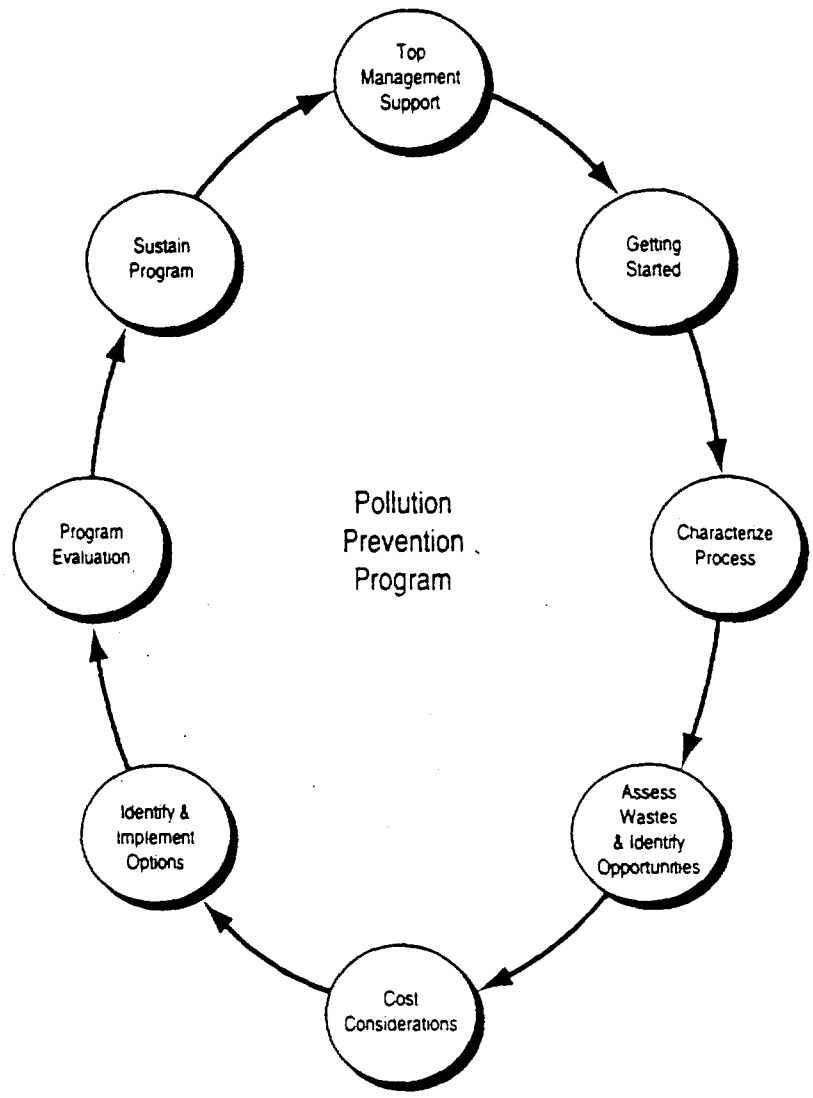

Figure 8-2. The continuous pollution prevention loop.

internal framework upon which a solid and enduring program can be built. The initial groundwork includes developing awareness and understanding of pollution prevention among top management. Providing a concise oral or written presentation about pollution prevention and how such a program can benefit the company can serve as an introductory overview. Figure 8-3 provides a checklist of topic suggestions.

Cost savings through reduced raw material usage, and reduced waste-handling, transportation, and storage costs
Increased productivity
Improved product quality
Regulatory compliance
Worker health and safety
Reduction of potential long-term liability
Examples of what other similar companies have achieved
Improved public image for the corporation
Emphasis of EPA policy on pollution prevention as a priority for the 1990s
Current state policies regarding pollution prevention planning

Figure 8-3. Suggested pollution prevention topics to discuss with management.

One way to follow up such initial presentations is to highlight pollution prevention case studies from companies using similar industrial processes. Seeing other successes can demonstrate the practicality of pollution prevention and provide tangible bottom line results. Case study examples are available from state pollution prevention agencies and the U.S. Environmental Protection Agency (EPA). Trade associations may also have case studies available specific to their industries.

Seeking assistance from state environmental agencies, both regulatory and nonregulatory, that offer pollution prevention services can be considered a next step. Staff from these agencies, consultants, and industry pollution prevention experts can be invited to talk to management about developing a pollution prevention program.

Once management approves a pollution prevention program, the foundation is complete and the first floor is ready to be built. Management's role is far from over, however. A brief written policy statement in support of a pollution prevention program needs to be drafted. Endorsements of the policy by all management levels are needed, and then the policy should be distributed to all employees. This statement can be a useful tool used for increasing employee awareness of pollution prevention.

Depending on the company's organization and structure, developing a corporate policy statement can be a lengthy process. Rather than allow this procedure to delay proceeding with the program, an interim policy or area-specific policy can be developed. This gets the program started; the corporate policy can follow later. Figure 8-4 shows an example of a management policy statement.

We, [company name], are committed to excellence and leadership in protecting the environment. In keeping with this policy, our objective is to reduce waste generation and emissions. We strive to minimize adverse impact on the air, water, and land through excellence in pollution prevention. By successfully preventing pollution at its source, we can achieve cost savings, increase operational efficiencies, improve the quality of our products and services, and maintain a safe and healthy workplace for our employees.

[Company name]'s environmental guidelines include the following:

- Environmental protection is everyone's responsibility. It is valued and displays commitment to [company name].
- Preventing pollution by reducing and eliminating the generation of waste and emissions at the source is a prime consideration in research, process design, and plant operations. [Company name] is committed to identifying and implementing pollution prevention opportunities through encouragement and involvement of all employees.
- Technologies and techniques which substitute nonhazardous materials and utilize other source reduction approaches will be given top priority in addressing all environmental issues.
- [Company name] seeks to demonstrate its corporate citizenship by adhering to all environmental regulations. We promote cooperation and coordination between industry, government, and the public toward the shared goal of preventing pollution at its source.

Figure 8-4. A management policy statement. (*From Minnesota Office of Waste Management, 1991.*)

Additional support needed from management includes assigning responsibility for developing the pollution prevention program, developing a means for evaluating and tracking progress, allocating adequate time and budget, and recognizing achievements. Continuity of the pollution prevention program is important. From the initial stages, the program should be set up in such a way that one step can flow naturally into the next in a continuous cycle.

When a pollution prevention program flows from one step to the next, it comes to be viewed by all personnel at the facility simply as their way of doing business. One way to introduce pollution prevention into the company psyche is through incorporating it within a total quality management (TQM) program. It also builds nicely on a health or environmental safety program because it can benefit the company in a number of ways as shown in Fig. 8-5. Whether pollution prevention becomes integrated into another program or stands alone, it is a group effort with all employees working together toward meeting company pollution prevention goals.

Pollution prevention reduces the amount and/or toxicity of chemicals in the workplace.

Pollution prevention reduces short- and long-term exposure of employees, visitors, and contractors.

Pollution prevention reduces or eliminates monitoring requirements.

Pollution prevention reduces reporting requirements.

Pollution prevention reduces toxics, thereby reducing HVAC requirements needed.

Pollution prevention reduces or eliminates the need for personal protective equipment.

Figure 8-5. Why pollution prevention can be incorporated into a company's health and safety program.

8.5 Getting Started

Once a policy statement has been written, approved, and distributed, the process of incorporating a pollution prevention program into daily company activities begins. The steps involved include designating a pollution prevention coordinator, developing a pollution prevention team, increasing employee awareness and involvement, establishing a recognition program, training employees, goal setting, and developing a written pollution prevention plan.

8.5.1 Designate a Pollution Prevention Coordinator

While a pollution prevention program needs top-down support and commitment, it also needs bottom-up input and implementation. This means that teamwork and participation from all levels within the company are essential. A key element for success is to find a good advocate and coordinator for the pollution prevention program.

The pollution prevention coordinator will be responsible for establishing the pollution prevention team(s), conducting meetings, and making sure the company is working toward its pollution prevention goals. More than likely, the coordinator will come from a middle-management position. He or she needs to be well organized, an advocate for the program, enthusiastic, and a motivator of people. If the coordinator has top-management support and the confidence of supervisors and others on the team, he or she will likely develop a very successful program. The coordinator will act as the key liaison to top management. This helps to ensure that the best pollution prevention ideas in terms of need, feasibility, and benefit to the company are delivered to top management for consideration. Also, the coordinator will need to obtain interdepartmental cooperation and resources on a continuing basis.

8.5.2 Develop a Pollution Prevention Team

A pollution prevention team needs to be organized prior to beginning the characterization and assessment processes. The team should not be assigned from any one department. Some suggested key personnel to include are representatives (both supervisors and line workers) from maintenance, production, environmental, health and safety, purchasing, shipping and receiving, legal, and engineering departments. Plant and executive managers should also be included. Not every company will have all these designations; the point is to include those individuals knowledgeable about the processes generating wastes and involve them from the beginning.

The initial pollution prevention team meeting should be an informal session to discuss the concept of pollution prevention, how the company can be expected to benefit, and where and how to begin. General information about the company's processes and operational procedures should be reviewed. The team will be responsible for developing the formal pollution prevention plan as discussed later.

In addition to those individuals assigned duties on the pollution prevention team, others may wish to help. Do not turn away volunteers—everyone should be encouraged to participate in the pollution prevention program. All volunteers should be commended in some way (in articles in the in-house newsletter, for example) for their ideas and interest in helping the company, their coworkers, and the environment. Employee suggestions should continually be encouraged—supervisors need to listen carefully because innovative ideas can come from any employee. Pollution prevention must continue for the life of the facility; establishing a sound, cooperative program from the start will be beneficial in future years.

8.5.3 Develop a Written Pollution Prevention Plan

After the pollution prevention team has been organized, development of a written plan should be its first official task. (Some states now require facility pollution prevention plans.) The written plan should include all the ideas developed by the team, such as the statement of support from management; the pollution prevention team's structure, organizational guidelines, and statement of purpose; the methods for fostering participation by all employees; the company's general goals; the structure of an incentive and/or award program; the procedures for conducting process assessments; selection of projects; procedures, criteria, and schedule for implementing pollution prevention projects; and provisions for employee training. Again it should be emphasized that the plan must contain clear guidelines for employee participation on the team, as well as criteria for selecting and implementing projects. There should also be provision for replacing team members as necessary.

Maintaining a pollution prevention program requires that the plan be an accepted part of company procedure. This plan should be presented and agreed to by management so that they understand how the pollution prevention team will proceed and what resources and support will be required. Copies of the plan can be made available for all employees to read if they so desire. The plan should be modified on an annual basis as pollution prevention experience is gained and goals are reached. A company should strive to continually improve the entire program.

8.5.4 Set Goals

There are different types of goals a company should set when beginning its pollution prevention program. Some goals will be waste-specific, such as replacing organic cleaning solvents with water-based alternatives or replacing a wet paint line with powder coating. Other goals will be activity oriented such as establishing a preventive maintenance program, incorporating pollution prevention into performance evaluations of all management staff, installing a revised accounting system that charges the cost back to the production line generating the waste, training all employees in pollution prevention, or holding monthly team meetings.

The team should discuss what types of goals are appropriate for the company. For example, a company may want to set an ultimate goal of "zero percent waste generation" to acknowledge the fact that pollution prevention is a continuous quality management program. This is very similar to company goals like "zero product defects" or "zero lost workdays." Another goal may be to replace some or all toxic substances used with less toxic substances and thus reduce risk to employees, the public, and the environment. Specific goals will also be based on the type of production process undergoing change, for example, replacing hexavalent with trivalent chromium in a plating line.

In addition to specific goals, more general goals should be set. These could include improving worker health and safety in the facility or improving the company image and attractiveness to investors.

It is a good idea to set a number of measurable goals to track progress over a given period. Numerical goals for waste reduction may be established once the wastes are characterized. Goals should be continually updated as they are achieved. Do not remain static. Build on the successes achieved.

8.5.5 Increase Employee Awareness and Involvement

One method of increasing pollution prevention knowledge is through a corporate and/or facility awareness program. Supervisors should discuss the status of the pollution prevention program at weekly meetings. They should encourage employees to bring pollution prevention ideas to them so they can be for-

warded to the facility pollution prevention team meetings. Some companies may already have "quality circles" in place to improve product quality and production efficiency. The team should work with these groups to develop ideas for pollution prevention initiatives. Figure 8-6 provides suggestions for the pollution prevention team to use in developing its awareness program.

8.5.6 Train Employees

As pollution prevention strategies are identified, the training requirements must be considered by the pollution prevention team prior to implementation. Pollution prevention training programs should be tailored for management, line, and maintenance staff and should be incorporated into company procedures. This training can be incorporated into other training programs, such as process operation training or health, safety, and environmental training. Consolidated training for different groups can also stimulate discussion between employees who would not interact otherwise. Additional personnel training may be needed if materials-handling or accounting changes are made.

Provide a definition and explanation of the primary components of pollution prevention: source reduction and in-process recycling.

State company policies and guidelines clearly.

Mention any state government requirements for pollution prevention planning.

Identify company goals to reduce waste generation and to improve operations.

Stress that pollution prevention is essential and benefits the company.

Encourage employee participation as extremely important to improve facility and environmental conditions.

Distribute information on pollution prevention and the company's commitment to all employees.

Make management and pollution prevention team members available to respond to employee suggestions and new ideas.

Present facts on safety improvement that occurs when a pollution prevention program is implemented.

Stress the relationship between the cost of generating waste and company competitiveness.

Equate savings from pollution prevention with the company's fiscal health (i.e., increasing job security to encourage employee involvement).

Figure 8-6. Building a pollution prevention awareness program.

The facility or company may want to include a pollution prevention orientation program for all new employees, regardless of their job function. Employees will need thorough training on any new technologies or techniques added to unit processes. Depending upon the size of the facility, this may require training on more than one shift.

8.5.7 Reward Pollution Prevention Successes

To generate interest and participation in pollution prevention, establish an employee award or recognition program. Competition at larger plants may motivate participation. Shifts, departments, or even individuals can be encouraged to compete against their own past year's performance. Recognition in the form of an awards ceremony, a bonus, company logo merchandise, a special parking place, or added vacation time provides a tangible reward to individuals and departments who have reached their pollution prevention goals. Further recognition may be promoted in a regular column in the company newsletter. When a company newsletter is not available, a one-page fact sheet on pollution prevention could be started that acknowledges employee participation and accomplishments.

8.6 Out in the Plant—A Learning Process

This chapter focuses on the first two steps, top-management support and getting started, and the last step, sustaining a program, from the eight-step program used by HWRIC. A brief overview of the remaining five steps is provided below. In-depth procedures on approaching each aspect of a pollution prevention program are found elsewhere in this handbook.

8.6.1 Step 3: Characterize Process

To effectively implement a pollution prevention program, it is necessary to develop a complete understanding of the various unit processes and points in these processes where waste is being generated. The team should characterize all processes in the facility and keep these characterizations updated as process changes are made.

Two general approaches to characterize processes and waste generation are used. One technique involves gathering information on total multimedia (air, land, and water) waste releases at the end of each process, and then backtracking to determine waste sources. The other technique utilizes tracking of materials from the point where they enter the plant until they exit as wastes or products. Both techniques provide a baseline for understanding where and why

wastes are generated, and a basis to measure waste reduced after implementation of pollution prevention projects. The steps involved in these characterizations include gathering background information, defining a production unit, general process characterization, understanding unit processes, and completing a material balance.

Developing process flow diagrams or updating existing diagrams can be useful for determining where, why, and how much waste is generated. The information assembled in the process characterization and flow diagrams will be used to help identify pollution prevention opportunities.

8.6.2 Step 4: Assessing Waste and Identifying Pollution Prevention Opportunities

Before conducting an assessment to identify what pollution prevention opportunities are present, wastestreams and unit processes should be prioritized to determine which should be examined first. When establishing priorities for pollution prevention, all input and output streams should be ranked—beginning with those which require immediate attention, followed by those which are less urgent. The team should maintain this list of priorities, so that once a project is completed they can move on down the list. The team should also update this list, as priorities may change with new regulations, changes in business direction, and other factors. It is also important, however, for the company to identify easy-to-do projects that can reduce waste and save money. Implementing these projects first can yield early successes in the program. Many of these types of changes can be started at the same time as more involved projects.

Once wastestreams are identified and prioritized, the assessment of specific pollution prevention opportunities can begin. This procedure involves looking at the specific processes contributing to the candidate streams. The team needs to observe the process in operation—ideally during all shifts, and if possible during a shutdown/cleanout/start-up period—to identify materials used and wastes generated by these procedures. Figure 8-7 lists what the assessment teams should be looking for.

Generate Reduction Options. Once the process assessments are complete, the data should be reviewed for thoroughness by all pollution prevention team members. This review will aid the next activity: brainstorming for ideas to reduce waste and/or eliminate toxic and hazardous materials. Team members should also solicit ideas from personnel at all levels throughout the facility. Many times these personnel already have ideas for reducing waste but have never had the opportunity to express them. All options should be written down and given serious consideration.

Observe operation procedures of line workers.

Determine quantities and concentrations of materials (especially wastes).

Observe collection (including exact sources) and handling of waste (note if wastes are mixed).

Examine any recordkeeping; obtain copies of records if this has not been done already.

Create flow diagram and follow through actual process.

Look for any leaking lines or poorly operating equipment.

Look for any spill residues.

Examine any damaged containers.

Determine physical and chemical characteristics of the waste or release.

Figure 8-7. Process assessment observations.

8.6.3 Step 5: Cost Considerations

Before pollution prevention projects are evaluated for economic feasibility, the full cost of waste generation must be determined. This full cost is necessary to develop the economics of pollution prevention techniques and technologies, including calculating the cost savings and payback periods.

Determine Full Cost of Waste. The full cost of waste generation includes more than treatment or disposal costs; it includes all the costs incurred in producing and handling waste. All of the expenditures associated with the wastestream, both direct and indirect, should be identified. These include, but are not limited to, the following: purchasing, storage and inventory, and in-process use of materials; air and water emissions, solid waste collection, waste storage, and on-site treatment or recycling; waste disposal; waste transportation; lost raw materials; labor costs. A pie chart showing the typical cost for waste generation is shown in Fig. 8-8. Often, wasted raw material costs are three-fourths of the full cost of generating waste. Waste disposal costs are typically less than half the total costs (Selman and Czarnecki, 1988). Many pollution prevention options will not appear to be justified if only half, or less, of the likely savings are considered.

Develop Economics. Once the full costs of the wastestreams are determined, an economic analysis of each pollution prevention project can be conducted. This analysis will provide management information on the costs and benefits associated with the techniques and/or technologies so that management can decide whether it is economically feasible to proceed with implemen-

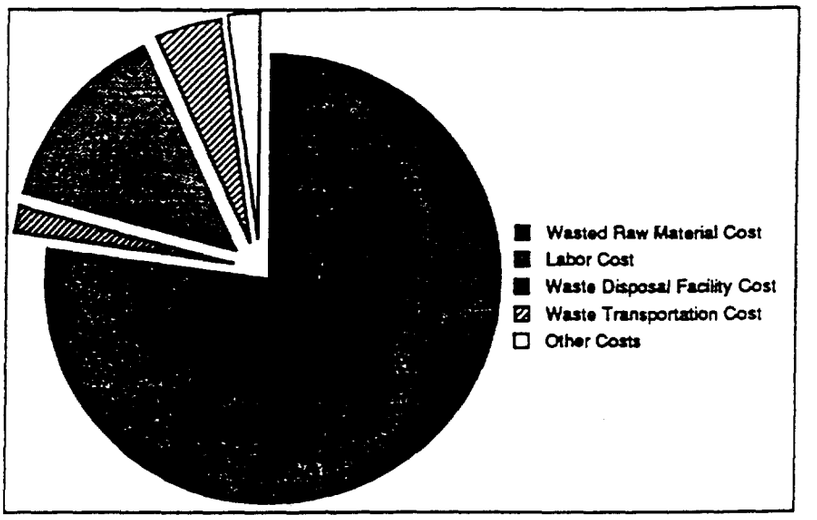

Figure 8-8. Typical cost distribution for waste generation.

tation. Certain benefits, such as reduced long-term liability, reduced worker exposure to toxic chemicals, and improved community relations, will be difficult to quantify.

Establish Cost Allocation System. A cost allocation system is an important element of a pollution prevention program. In this system, each department or process is charged for the total waste management costs of the wastes it generates. This cost allocation system should lower the total overhead cost, as most companies charge waste disposal costs to overhead (i.e., the environmental department), and may provide a more accurate idea of the total cost of waste generation at the facility. It will also provide incentives for employees associated with the departments or processes that are charged for the waste handling to reduce their waste generation and subsequently their costs.

8.6.4 Step 6: Identifying and Implementing Pollution Prevention Options

Once suggestions for pollution prevention options are gathered and the costs associated with these options calculated, they should be reviewed by the pollution prevention team and the least beneficial options eliminated. These options may, however, be reviewed in the future, as what is less beneficial now may work better later. Each remaining option should then be examined in more detail to determine its overall benefits. Technical and economic feasibility of

each option, based on the company's requirements for these criteria, should be studied. Those options found to be consistent with the company's goals can then be scheduled for implementation. There may even be cases in which certain benefits of a project override low economic return.

Some projects may be worth doing for reasons other than pollution prevention. For example, preventive maintenance programs can reduce the risk of leaks, spills, or possible explosions. Increasing process efficiency may improve economic competitiveness. These types of projects may also result in waste reductions. Regardless of the criteria for selection, any pollution prevention benefits associated with a project should be identified and documented.

Technical Evaluation. There are many factors which should be considered when one determines if a project is technically feasible. Personnel that will be directly affected by implementing the project should be consulted and included in the decision-making process. They typically have knowledge of process details that may inhibit project success and are essential in proper implementation. For projects that involve a new technology and/or technique, a bench-scale or pilot test may be required to assess technical feasibility. At this point, if it is determined that an option is not feasible by these criteria, the option should be deferred for consideration at a later time when the circumstances may be different.

Economic Evaluation. Once a pollution prevention project has been found to be technically feasible, the economics of the project should be examined.

Any project that yields a cost savings, i.e., savings in annual waste-handling or annual operating costs, has potential for profitability. If there are no initial costs involved, then a project can be considered economically feasible if there is a cost savings. Options such as better operating practices may be the most practical to implement first since they do not require an initial capital investment.

Implementing Projects. Once the pollution prevention team selects the projects to be implemented, management approval must be obtained. If management support was obtained as described previously, the approval process should not be difficult providing the project benefits, profitability, and feasibility are acceptable. The pollution prevention coordinator should present the details of the project along with the budget and project justification—particularly economics—to management. Once approval is received and implementation begins, it is important for team members to stay involved in the project. They should closely monitor all pollution prevention activities to make sure any problems are addressed immediately.

8.6.5 Step 7: Program Evaluation

The pollution prevention program should be continuously evaluated and updated to improve overall effectiveness. This periodic review by the pollution

prevention team should be conducted for all stages of the program, from management support and team selection to project implementation.

The progress of the pollution prevention program can be determined by looking at the individual activities and projects. One way of measuring progress is quantitative. For example, look at actual waste reduction, both in terms of actual change in quantity and change in hazard level. The actual change in quantity is the difference between the waste per production unit reported in the current year and the waste per production unit reported in the previous year. The change in hazard level is based on toxicity, reactivity, ignitability, and corrosivity of the waste and industrial hygiene/employee exposure–type measurements. This comparative measurement is most useful when one evaluates an alternative material substitution, such as switching from an organic solvent to a water-based solvent. (Switching to water may even eliminate an OSHA sampling requirement.) These measures of waste reduction may not be appropriate for all facilities and wastes. Other quantitative measurements are adjusted quantity change and throughput ratio. Additional guidelines and detailed descriptions on measuring pollution prevention progress can be found in other chapters of this handbook.

When evaluating the elements of the program, it is important to identify those strategies and techniques which have been very successful, marginally successful, or have failed. If possible, the reasons why these projects were or were not successful should be determined. This information will be beneficial for modifying the program and redefining goals.

8.7 Sustain the Pollution Prevention Program

A pollution prevention program, once initiated, should have no "last step." Rather, the challenge lies in continuing and increasing the forward momentum cycle after cycle. Specific projects may be completed, but new projects should always be under development. The pollution prevention program cycle involves maintaining a strong commitment to the program from all operating levels. Some specific ideas for sustaining the program while carrying employee participation forward include summarizing the economic benefits of the program, bringing new personnel into the pollution prevention team, providing additional training, and publicizing success stories.

8.7.1 Reemphasize Economic Benefits

To sustain momentum in the pollution prevention program, the economic benefits realized through the activities undertaken should be summarized and presented not only to management personnel but to all employees. This information will also be important to include in the annual report to stockholders.

Emphasize cost savings resulting from pollution prevention projects over what would have been spent prior to implementation. Continue to track cost savings on implemented projects, as this may be the primary driving force toward sustaining the program.

8.7.2 Rotate Pollution Prevention Team

To maintain the flow of fresh ideas and introduce new perspectives, the pollution prevention team members should be rotated. With an ongoing pollution prevention program, there may be new employees who join the company over the years that want to participate. It is especially important that if the primary advocate and/or team leader for the pollution prevention program steps down, management find a suitable replacement who will give the program high priority and active guidance. A new team leader should step in with high energy, enthusiasm, and creativity. As members step down, they should be encouraged to serve as "consultants" to their replacements. There may also be team members who wish to remain; this should be encouraged, as they have gained valuable field experience. Team composition should always include employees from all levels and departments. The importance of having a written pollution prevention plan in place can be better understood once there is turnover of team members. This document provides the blueprint for operating the pollution prevention program and provides necessary continuity when there is a shift in team members.

8.7.3 Provide Refresher Training

Pollution prevention awareness and training should be conducted on a periodic basis so that all new or reassigned employees understand the company's commitment to the program and their individual responsibilities. As discussed earlier, pollution prevention training can be incorporated into already existing training programs (health and safety, environmental, processes, etc.) if that works best for the company.

8.7.4 Publicize Success Stories

Publicity is one of the most effective means to sustain the pollution prevention program. Internal publicity raises employee awareness of activities at the facility and encourages further participation. The results of the various projects should be relayed through bulletin board postings, newsletters, interoffice memos, and so forth. The names of the pollution prevention team members, as well as those employees offering suggestions, should be included in these publications. Hold periodic special events such as a free lunch for all employees contributing pollution prevention ideas during a specified month. If individual

successes are recognized, other employees may wish to join in to receive the same recognition. Award ceremonies for employees or teams that have met their pollution prevention goals will also help publicize successes. Cost savings, waste reductions, and product quality improvements due to pollution prevention activities and projects should be highlighted.

The pollution prevention program can be a key public relations tool. Any reduction in waste is a benefit to employees, the community, and the environment, and should be publicized. News releases should be prepared for local and state news media documenting the project and the benefits to the company and the surrounding community. Reporters could also be invited to the facility for a demonstration of a new technology. Community forums such as city council meetings or local chamber of commerce meetings are excellent avenues to promote the company's environmental efforts.

Further public recognition can be facilitated through state, county, and local award programs. Pollution prevention award programs can be found in many states. These awards are presented to industrial facilities, trade organizations, vendors, community groups, and educational institutions that demonstrate significant achievements in pollution prevention. Check with the agency in your state responsible for overseeing pollution prevention activities on whether or not an award program exists.

Trade association meetings and publications are another good avenue for promoting a company's pollution prevention program. Case studies can be submitted which demonstrate the company's progressive stance in environmental protection while describing the use of innovative technologies and techniques to reduce waste. These case studies should emphasize the benefits accruing to the company—not only waste reduction but also cost savings, quality improvements, safety improvements, regulatory compliance, and better community relations.

8.8 Summary

The development of a pollution prevention program can involve a significant change in a company's traditional business practices. Whereas regulatory compliance has usually been the responsibility of an environmental department or coordinator, pollution prevention must involve employees from all areas of the plant and levels of management, including hourly workers. For companies developing TQM or continuous quality improvement programs, pollution prevention can become a part of these programs. A pollution prevention program can also become the primary strategy a company uses to achieve and maintain regulatory compliance. In fact, it may allow companies to get out of the regulatory system altogether.

As discussed, a pollution prevention program requires a firm commitment from management to survive. A written plan which affirms this commitment, provides guidance for conducting the program, lists criteria for evaluating and

selecting projects, and gives procedures for documenting successes and failures is essential. A key component in every successful program is the pollution prevention advocate. The company must choose a program leader who understands and believes in a pollution prevention approach and who has the ability to work with people at all levels of the organization to implement the program.

A fully implemented pollution prevention program will affect a company's relationship with its suppliers, customers, and neighbors. A facility may even consider its neighbors to be its customers and thus inform them of the facility's activities and solicit their input. Community relations can be an important part of a company's pollution prevention program and can help sustain the program.

A company can also apply pressure to its suppliers and vendors to have them adopt pollution prevention programs and can encourage them to develop pollution prevention solutions for products and processes that may create significant amounts of hazardous and/or toxic wastes. The company can also look into providing "green" products and marketing them as such. For example, one company abandoned its line of organic solvents and now manufactures solvents with an aqueous base that do not generate hazardous waste. These cleaner solvents are now in great demand by many companies around the country. Companies with "green" products may find their pollution prevention approach to doing business will be sustained as it becomes an essential part of their business practice. This is the ultimate key to maintaining a successful pollution prevention program.

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12

Facility Pollution Prevention Planning

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12.1 Developing a Pollution Prevention Program

Pollution prevention planning is a comprehensive and continual evaluation of business operations. The resulting pollution prevention program affects many functional areas within a company, such as the production line, accounting practices, and management. It has much in common with the planning already conducted for other aspects of business operations, but it looks at the facility as an integrated whole instead of as a series of disjoint parts or operations.

Figure 12-1 is a flowchart illustrating the major elements in the pollution prevention program. This section describes the elements of pollution prevention program planning and design. These elements include building support for pollution prevention throughout the company, organizing the program, setting goals and objectives, performing a preliminary assessment of pollution prevention opportunities, and identifying potential problems and their solutions.

12.1.1 Establish the Pollution Prevention Program

Executive Level Decision. In some companies, the initiative for setting up a pollution prevention program will be taken at the executive level. In others, lower-level managers or employees will be the catalysts. In either case, it may

Source: Freeman, Harry; Industrial Pollution Prevention Handbook

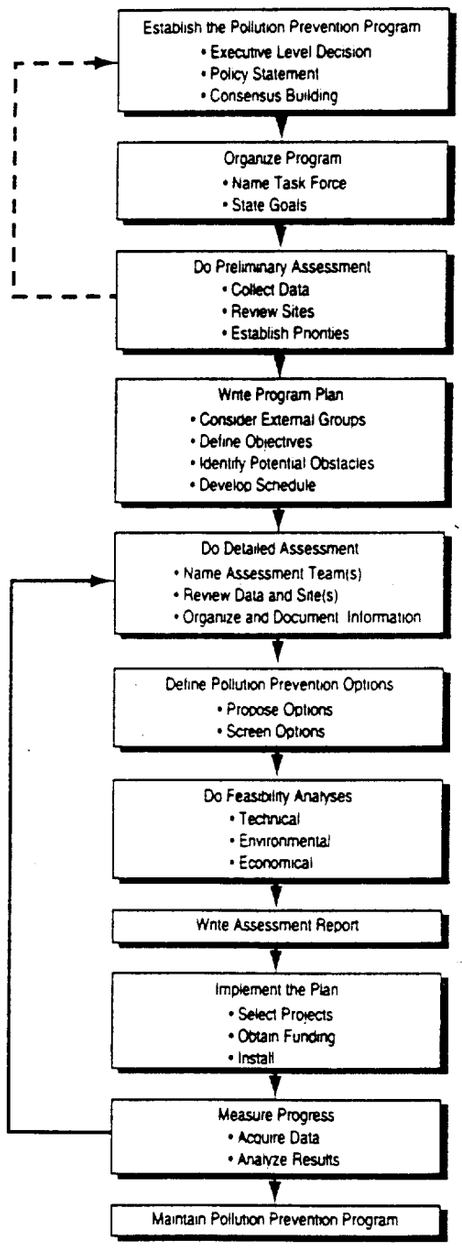

Figure 12-1. Major elements of a pollution prevention program.

be necessary to gather preliminary information to demonstrate that pollution prevention opportunities exist and should be explored. This preliminary information will be used by company executives as they weigh the potential value of pollution prevention and decide whether to commit the resources necessary to develop and implement the program.

One way to gather this information is to perform a preliminary assessment of only one or two areas of the facility and, perhaps, even identify several low-cost, quick-payoff pollution prevention techniques that can be implemented readily. A preassessment is part of the formal program design effort and is, therefore, described later in this section.

Once the decision to establish a pollution prevention program has been made it should be conveyed to all employees through a formal policy statement. This establishes a framework for communicating the formal commitment throughout the organization.

Policy Statement. As with other company policy statements, the pollution prevention policy statement should state:

- Why a program is being established
- What is to be accomplished in qualitative terms
- Who is responsible for pollution prevention

Consensus Building. After the pollution prevention policy statement has been developed, consider how it should be presented to employees so that they will see it as an ongoing, companywide commitment. While the priorities and tone of the pollution prevention program will be set by the management team, the attitude of production-level employees will have a significant effect on its success. Since it is through their daily activities that waste is generated, their support of the program is essential.

Publication or distribution of the policy depends on the size and the culture of your company. Suggestions include a general meeting or several small group meetings, distribution via a company newsletter, a special insert with a paycheck, or other types of publicity that have been found effective.

Employee incentives for continued participation and to keep interest from waning are necessary. Bonuses or other awards might be offered to employees who suggest ways to prevent pollution. Announcing awards in newsletters or on bulletin boards provides additional incentive to employees and further publicizes the program. Finally, pollution prevention should be included in job objectives and performance evaluations for all employees.

The company's commitment to pollution prevention cannot be overemphasized and neither can the need for employee participation. This will help to establish a positive atmosphere, will reassure employees concerned with resulting changes, and will also elicit worthwhile pollution prevention suggestions.

Employees' participation should be encouraged at all stages of the pollution prevention program including:

- Defining company goals and objectives
- Reviewing processes and operations for use and generation of pollutants or emissions
- Recommending ways to eliminate or reduce waste production at the source
- Designing or modifying forms and records to monitor materials used and waste produced
- Finding ways to involve suppliers and customers
- Acknowledging and rewarding employee contributions to the pollution prevention effort

12.1.2 Organize the Pollution Prevention Program

The program will be directed by the pollution prevention task force. Its first task will be to delineate program goals.

Name the Pollution Prevention Task Force. The people who will direct the pollution prevention program should be selected carefully. They will have overall responsibility for developing the plan and directing its implementation. Their capabilities and their attitudes toward the effort will be major determinants of how successful it is.

As with other areas of your operation, successful program execution will require integration and continuity through planning, implementation, modification, and maintenance. Therefore, all individuals named to this task force should have substantial technical, business, and communication skills as well as thorough knowledge of the company. The responsibility and authority of each individual should be established during this organizational stage.

Once the task force has been established, it will be a valuable resource within the company both now and in the future. When plans are being made to expand the facility or to design or redesign products, the task force can review the plans to determine whether pollution prevention opportunities have been evaluated thoroughly.

Program Leader. The role of the leader is to facilitate the flow of information among all levels in the company. The program leader's responsibilities include keeping the program on track, and ensuring that pollution prevention becomes an integral part of the overall corporate plan. The program leader's attributes should include a high degree of authority within the organization and the personal qualities necessary to elicit broad-based support from the company's employees.

Champion. The task of a "champion" is to overcome possible resistance to proposed changes in operations. Champions will be the task force members who serve as liaisons and should be visible within the production areas and respected and trusted at all levels.

Team Members. Other task force members might be selected for their specific technical or business expertise. Potential task force members include environmental and plant process engineers, production supervisors, health and safety personnel, experienced line workers, and purchasing and quality-assurance staff.

In some cases, it may be necessary or desirable to retain outside consultants to work with the in-house task force when suitable skills are not available within the company.

State Goals. The task force members, with input from concerned employees and management, will need to establish goals that state the long-term direction for the pollution prevention program. Goals, which may have been stated in general terms in the policy statement, now need to be stated more specifically. This will help to focus effort and build consensus.

A starting point for establishing pollution prevention goals is the zero-discharge perspective. This ideal situation would involve 100-percent utilization of resources, eliminating disposal costs and regulatory compliance needs. However, like zero-defect production goals, zero-discharge goals are not achievable given the current technology, but serve to encourage an attitude of continually striving for improvement.

Goals can be *qualitative*, such as to "achieve a significant reduction of toxic substance emissions to the environment," or *quantitative*, which are more difficult to develop but are worth the extra effort. Quantitative goals spell out your pollution prevention commitment and give all participants and observers a yardstick for measuring progress.

Finally, goals should be flexible and adaptable. Conditions change in actual practice and as information is acquired. As your pollution prevention program becomes more focused, the task force and program more mature, and the pollution-specific aspects of the operation become better known, the goals can be refined. Periodic review of the goals and the achievements by the task force, management, and the employees will keep your program active and visible within the company.

12.1.3 Do the Preliminary Assessment

Even though some aspects of the preliminary assessment may have been completed as input to the executive decision to develop a pollution prevention program, a deeper examination is needed. Data collection as part of the preassessment serves two purposes: (1) to help the task force review the data that are already available, and (2) to begin defining ways to process that data. These

data, along with site visits, will enable the task force to establish priorities and procedures for detailed assessments. Chapter 13 describes the detailed assessment phase and the more in-depth data collection and analyses that will be done at that stage.

Collect Data. The extent and complexity of the system used for collecting pollution prevention data should be consistent with the goals of the pollution prevention program and the needs of the company. The objective of the program is to prevent pollution, not to collect data. Use the simplest system that is consistent with the goals and needs. Depending on the nature and size of the firm, much of the data needed for a pollution prevention program may already have been collected as a normal part of plant operations or as part of a response to existing regulatory requirements.

An all-media approach, which considers all air, water, and solid waste emissions and releases, will be the most effective. For each wastestream, the sources are identified, the methods for pollution abatement are evaluated, and the true costs of abatement, treatment, and waste disposal are quantified. A number of information sources to consider are outlined in Fig. 12-2.

Regulatory Reports. National Pollutant Discharge Elimination System (NPDES) and SARA Title III reports document the volume, composition, and degree of toxicity of wastewater discharged. The toxic substance release inventories required by SARA Title III, Sec. 313, may provide information on emissions into all environmental media.

Engineering and Operating Data. Shipping manifests will provide quantities of hazardous waste shipped during a given period, but may not provide information on the chemical analysis, specific source, and the time period during which the waste was generated. The plant design documents and equipment operating manuals and procedures may yield specific data for streams inside of the plant.

Plant Business Records. Records available from inventory control, purchasing, records management, accounting, marketing, and training can provide data needed for the preassessment and may themselves present opportunities for pollution prevention. For example, improved inventory control and judicious purchasing can significantly reduce the volume of raw materials that must be disposed of because they become outdated. In reviewing existing data, you may find that current accounting practices are not appropriate for placing the burden of pollution and pollution control at the point of generation. These findings should be taken into account when costs of pollution control measures are analyzed. (See Chap. 16.)

Visit Sites. Part of the information the task force will need in order to prioritize the processes, operations, and wastes that will be studied during the detailed assessment phase should be garnered by a site visit by the task force. During this phase, the most important waste problems should be targeted, with lower-priority problems dealt with as resources of time, staff, and money per-

Data Sources for Facility Information

Regulatory information:

- Waste shipment manifests
- Emission inventories
- Biennial hazardous waste reports
- Waste, wastewater, and air emissions analyses, including intermediate streams
- Environmental audit reports
- Permits and/or permit applications
- Form R for SARA Title III, Sec. 313

Process information:

- Process flow diagrams
- Design and actual material and heat balances

Raw material/production information:

- Product composition and batch sheets
- Material application diagrams
- Material safety data sheets
- Product and raw material inventory records
- Operator data logs
- Operating procedures
- Production schedules

Accounting information:

- Waste handling, treatment, and disposal costs
- Water and sewer costs, including surcharges
- Costs for nonhazardous waste disposal, such as trash and scrap metal
- Product, energy, and raw material costs

Figure 12-2. Information sources for preliminary assessments.

Typical Considerations for Prioritizing Wastestreams for Further Study

- Compliance with current and anticipated regulations
- Costs of waste management (pollution control, treatment, and disposal)
- Potential environmental and safety liability
- Quantity of waste
- Properties of the waste (including toxicity, flammability, corrosivity, and reactivity)
- Other safety hazards to employees
- Potential for pollution prevention
- Potential for removing bottlenecks in production or waste treatment
- Potential recovery of valuable by-products
- Available budget for the pollution prevention assessment program and projects
- Minimization of wastewater discharges
- Reduction of energy use

Figure 12-3. Considerations for prioritizing wastestreams.

mit. The preassessment site visits will provide the information needed to accomplish this prioritization and to designate the detailed assessment teams, which will be selected on the basis of expertise in particular areas.

Establish Priorities. Assigning priorities (see Fig. 12-3) to processes, operations, and wastestreams will focus the remainder of the pollution prevention plan development effort. The priorities set in this stage will guide the selection of areas for detailed assessment.

12.1.4 Prepare the Program Plan

With the information collected during the preassessment, the task force can develop a detailed program plan. This plan will address the extent to which external organizations will be involved, define pollution prevention program objectives, identify potential obstacles and solutions, and define the data collection and analysis procedures that will be used. A summary of the points that should be addressed in a program plan appears in Fig. 12-4.

Contact External Groups. At this point, the task force should consider soliciting input from outside the company. Inclusion of the surrounding com-

Elements of the Formal Written Pollution Prevention Plan

- Corporate policy statement of support for pollution prevention.
- Description of your pollution prevention planning task force makeup, authority, and responsibility.
- Description of how all of the groups (production, laboratory, maintenance, shipping, marketing, engineering, and others) will work together to reduce waste production and energy consumption.
- Plan for publicizing and gaining companywide support for the pollution prevention program.
- Plan for communicating the successes and failures of pollution prevention programs within your company.
- Description of the processes that produce, use, or release pollutants, including clear definition of the amounts and types of substances, materials, and products under consideration.
- List of treatment, disposal, and recycling facilities and transporters currently used.
- Preliminary review of the cost of pollution control and waste disposal.
- Description of current and past pollution.

Figure 12-4. Elements for a pollution prevention plan.

munity in the pollution prevention planning process can create a new forum for communication. Valuable technical information can also be exchanged with technical, trade, or professional organizations.

Legislative and executive officials can provide their perspectives on environmental protection issues and information on their planning processes. In return, they can gain information that will help them make decisions on future public issues related to the environment.

Community involvement is a good way to build credibility and focus pollution prevention efforts on the discharge paths that most concern your neighbors. However, it may be wise to wait until the program is established before seeking to involve the community. Having a few pollution prevention projects underway will demonstrate your good faith. Positive community involvement can be encouraged through holding open meetings, granting interviews to the media, advertising, circulating direct-mail surveys, and conducting opinion polls.

Other businesses can be sources of information on technical issues and suppliers, either because they are in the same geographical area or because they have similar technical areas of interest. Local business groups are a good way of locating resources in the immediate area, while trade and professional associations can provide contacts in other parts of the country or the world. Of course, the

companies with the most similar interests may be competitors, but it should be possible to interact without risking disclosure of business-sensitive information.

Define Objectives. During the preliminary assessment phase, the task force will have identified opportunities for pollution prevention and will have worked with the executive group to establish priorities. These will be the starting point for defining short- and long-range objectives.

Objectives are the specific tasks that will be necessary to achieve goals. For example, in order to reach a goal of reducing waste, the objectives might be defined as reducing solvent, paper, and packaging wastes by specific amounts over a stated period of time.

Objectives can be defined at the facility or the department level, depending on the size and diversity of your company. A small company could decide to develop a single set of objectives to cover all of its operations. A larger company with many facilities or products might develop an overall corporate plan describing goals and objectives, supplemented by facility- or product-specific goals. In any case, the management at each location must understand and support its objectives if the pollution prevention program is to be successful.

Objectives should be stated in quantitative terms and should have target dates. These two attributes make objectives effective tools for directing effort and measuring progress.

Identify Potential Obstacles. As the task force begins to develop and implement a pollution prevention program, a number of factors that will complicate the process will likely be encountered. These need to be recognized, and the means for overcoming them needs to be defined. Apparent obstacles will be less likely to impede the process if everyone understands that there is a mechanism for addressing them in a later stage.

The mix of factors and the relative degree of difficulty each presents will vary from company to company. Those that are likely to be encountered by most businesses are discussed here. They fall into four broad categories: economic, technical, regulatory, and institutional.

Economic Obstacles. The task force should recognize that some complex economic factors may need to be addressed later. Broadly defining procedures now for dealing with them will help prevent economic concerns from stifling the creative process of defining options.

Cost-benefit analysis procedures should be defined. Many proposed pollution prevention options will have start-up costs. For example, additional or replacement equipment may need to be purchased, staff training may be required, or alternative raw materials may cost more. Some of these additional costs can be justified readily because they clearly will be cost-effective and will have short payback times. However, many will not be so clear-cut and will need more sophisticated analysis as described in Chap. 15.

Limited financial resources for capital improvements may also be a problem, even for options that will ultimately be profitable. The task force should investigate the availability of and conditions for funding assistance or low-interest

loans from state or local agencies. Chapter 53 provides some additional information on whom to contact.

Technical Obstacles. Information will be needed on alternative procedures that should be considered, how to integrate them in the production process, and what side effects are possible.

Information resources could be a problem. As a small or medium-sized business, you may not have ready access to a central source of information on pollution prevention techniques. There are several ways to deal with this problem. Contact appropriate agencies listed in Chap. 53 for assistance. Encourage employees to watch for information in the technical journals and newsletters they read and to pass it on to the task force. Those who belong to professional societies may get ideas from other members. Metropolitan or university library reference departments can provide assistance in locating sources of published information as well as names of people who might be able to provide information in specific areas. If the scope of the technical problem and resources permits, it may be appropriate to retain a consultant.

Limited flexibility in the manufacturing process may pose another technical barrier. A proposed pollution prevention option may involve modifying the work flow or the product, or installing new equipment; implementation could require a production shutdown, with loss of production time. The new operation might not work as expected or might create a bottleneck that could slow production. In addition, the production facility might not have space for pollution prevention equipment. These technical barriers can be overcome by having design and production personnel take part in the planning process and by using tested technology or setting up pilot operations.

Product quality or customer acceptance concerns might cause resistance to change. For example, in some printing and publishing operations it is possible to minimize waste by substituting a water-based ink for a solvent-based ink. But for some products, quality suffers when water-based ink is used. Avoid potential product quality degradation by contacting customers and verifying customer needs, testing the new process or product, and increasing quality control during manufacture.

Regulatory Obstacles. Regulations may be a barrier to some pollution prevention options. For example, changing to another feed material may require changing the existing permits. In addition, it may be necessary to learn what regulations might apply to proposed alternative input materials.

Working with the appropriate regulatory bodies early in the planning process will help overcome this barrier. The EPA and the state environmental agencies have developed a number of documents to facilitate pollution prevention efforts by industry; many are listed in Chap. 53.

Local health department and city and county waste disposal and treatment offices may also provide assistance. Industry task forces and consultants might also be contacted.

Institutional Obstacles. As with any other new program, general resistance to change and friction among elements within the organization may arise. These can result from many factors, such as lack of awareness of corporate

goals and objectives, individual or organizational resistance to change, lack of commitment, poor internal communication, requirements of existing labor contracts, or an inflexible organizational structure.

Analyze these barriers from different perspectives in order to understand the concerns. Management is concerned with production costs, efficiency, productivity, return on investment, and present and future liability. Workers are concerned about job security, pay, and workplace health and safety. The extent to which these issues are addressed in the pollution prevention program will affect the success of the program.

Institutional barriers can be overcome with education and outreach programs. As was pointed out earlier, it is vital to gain the support of staff at all levels very early in the pollution prevention effort.

Develop Schedule. The final aspect of planning the pollution prevention program is to list the milestones within each of the stages from detailed assessment through implementation and then assign realistic target dates. The execution of these stages should follow this schedule closely. Significant deviations may cause the program to falter because certain steps are not completed. Adherence to the schedule will also help control the start-up or implementation costs of the program.

12.2 Developing and Implementing Pollution Prevention Projects

This section outlines how to execute the pollution prevention program plan that resulted from the activities already outlined.

As with the other stages, the degree of formality should be tailored to the size of the company and the diversity of its product lines. Thus, a small company may need to do only one detailed assessment and prepare one implementation plan, while a larger, more diverse company might require several in order to address all production processes. If multiple plans are developed, it will be necessary to examine how they fit together, resolving any conflicts and prioritizing them to fit available resources.

12.2.1 Detailed Assessment Phase

As part of the program design, a preliminary assessment of the facility identified areas of opportunity for pollution prevention. Now, detailed assessments will focus on specific areas targeted by the preliminary assessment.

Assessment teams will be assigned to each operational area of the facility to gather data for later analysis. As was the case during the preliminary assessment, existing written materials and site evaluations will be used. However, teams will delve much more deeply into each production process, interviewing workers and compiling necessary data that may not have been collected before.

During this process, the team may identify some options that can be implemented quickly and with little cost or risk. It is likely, however, that many options will be more complex and will require in-depth analysis later.

Detailed Assessment Team(s). The detailed assessment phase should be started by a member of the task force, which was identified during program design. Unless the company is small enough that the task force and the detailed assessment team are the same, additional staff (three to six individuals) will need to be named to form one or more detailed assessment teams which will focus on specific pollution prevention opportunities.

Ideally, one member of the task force will be included on each team to facilitate communication. The additional team members should be people with direct responsibility for and knowledge of the wastestreams and/or areas of the facility under consideration. To the extent practical, engineers, supervisors, and production workers as well as finance and accounting, purchasing, and administrative staff should be considered when the team members are selected, much the same as when the task force was chosen. A multidisciplinary team is likely to be more successful in achieving a comprehensive assessment and providing the best input possible to the data analysis and option definition stages. Specialists can be consulted as needed.

Aside from field of expertise, consider a candidate's ability to work on a team, apparent interest in and commitment to the program, and capacity for looking at situations from new perspectives and for thinking creatively. Some example teams are given in Table 12-1. Note that for each team, the team leader is someone who has day-to-day operations responsibility and experience.

Table 12-1. Examples of Detailed Assessment Teams

Metal Finishing Department in a Large Defense Contractor
Metal finishing department manager
Process engineer responsible for metal finishing processes
Facilities engineer responsible for metal finishing department*
Wastewater treatment department supervisor
Staff environmental engineer
Small Pesticide Formulator
Production supervisor*
Environmental engineer
Maintenance engineer
Cyanide Plating Operation
Environmental engineer*
Electroplating facility engineering supervisor
Plant chemist

*Recommended detailed assessment team leader.

Review Data and Sites. Numerous data sources probably exist for a given site. Many of these may have been identified during the preliminary assessment. The detailed assessment team for that site will search for additional sources of data that will be useful in studying the targeted processes, operations, or wastestreams.

However, most of their effort will be directed toward performing a thorough site review and interviewing workers. This will help them understand the data already collected and identify factors that are not well documented and for which data will need to be collected. Site review guidelines are outlined in Fig. 12-5.

A careful site review will provide the assessment team with a systems perspective of the process, operation, or wastestream in question and of how it fits into the overall facility operation. This perspective is a prerequisite for thorough assessment of options in later phases of the pollution prevention plan development cycle. If consultants are on the assessment team, the site review enables them to become familiar enough with the facility to utilize their expertise effectively.

The site review should not be performed perfunctorily, even though the assessment team members who are employed at the facility will all be familiar to some extent with the work site being reviewed. Those who are not involved in the day-to-day operation in that area will see factors that otherwise would be overlooked. Furthermore, personnel assigned to that specific site will often see it in a new

Site Review Plan

- Prepare an agenda in advance that covers all points that still require clarification. Provide staff contacts in the area being assessed with the agenda several days before the inspection.
- Schedule the inspection to coincide with the particular operation that is of interest (e.g., makeup chemical addition, bath sampling, bath dumping, start-up, or shutdown).
- Monitor the operation at different times during all shifts, and if needed, during all three shifts, especially when waste generation is highly dependent on human involvement (e.g., in painting or parts cleaning operations).
- Interview the operators, shift supervisors, and work leaders in the assessed area. Discuss the waste generation aspects of the operation. Note their familiarity with the impacts their operation may have on other operations.
- Photograph or videotape the area of interest, if warranted. Pictures are valuable in the absence of plant layout drawings.

Figure 12-5. Site review guidelines.

Typical Questions to Ask During Site Reviews

- What is the composition of the wastestreams and emissions generated in the company? What is their quantity?
- From which production processes or treatments do these wastestreams and emissions originate?
- Which waste materials and emissions fall under environmental regulations?
- What raw materials and input materials in the company or production process generate these wastestreams and emissions?
- How much of a specific raw or input material is found in each wastestream?
- What quantity of materials is lost in the form of volatile emissions?
- How efficient is the production process and the various steps of that process?
- Does mixing materials produce any unnecessary waste materials or emissions which could otherwise be reused with other waste materials?
- Which good housekeeping practices are already in place to limit waste generation?

Figure 12-6. Questions to ask during site reviews.

light when performing a pollution prevention assessment. Some of the information that can be gathered through site reviews is summarized in Fig. 12-6.

Site visits should be well planned to ensure that maximum benefit is obtained without excessive expenditures of time. While multiple visits to check or supplement data will usually be required, good planning can minimize such repetitions. Several suggestions for preparing for site visits are given here.

Review existing documentation, such as operators' manuals and purchasing and shipping records. This will enable the team to focus on the topics to be investigated. Decide on data collection formats to ensure that the data collection will be rigorous and compatible with the compilation and analysis stage described later. In particular, it is worthwhile to predetermine the boundaries and bases for calculating the energy and material balances that will be worked out during that stage. Doing a preliminary balance during the data collection phase can help identify data gaps and determine sampling requirements. Photographs and videos are an excellent means of capturing extensive detail quickly and accurately.

Prepare an agenda and make sure that all team members and supervisors at the site receive it in advance.

Schedule site visits by contacting the staff in the area to be visited. Ask when they will be performing the operations you are particularly interested in assessing.

Observe operations as they are actually performed by different shifts and under various circumstances. Process units may be operated differently from the methods described in their operating manuals, or the equipment may have been modified without being so documented in the flow diagrams or equipment lists.

Interview workers and supervisors to determine how aware they are of what wastes are generated by their operation. They may have suggestions for reducing these wastes.

Follow the process from beginning to end, from the point where input materials enter the work site to the point where products and wastes exit. This will help identify all suspected sources of waste. Waste sources to inspect include the production process; piping; maintenance operations; and storage areas for raw materials, finished product, and work-in-process. Examine housekeeping practices and the waste treatment area, as well. Make follow-up visits as missing or unclear data are identified during the analysis stage.

Organize and Document Process Information. Analyzing process information involves preparing material and energy balances as a means of analyzing pollution sources and opportunities for eliminating them. Such a balance is an organized system of accounting for the flow, generation, consumption, and accumulation of mass and energy in a process. In its simplest form, a material balance is drawn up according to the mass conservation principle:

$$\text{Mass in} = \text{Mass out} - \text{Generation} + \text{Consumption} + \text{Accumulation}$$

If no chemical or nuclear reactions occur and the process progresses in a steady state, the material balance for any specific compound or constituent is as follows:

$$\text{Mass out} = \text{Mass in}$$

The first step in preparing a balance is to draw a process diagram, which is a visual means of organizing the data on the energy and material flows and on the composition of the streams entering and leaving the system. Such a diagram shows the system boundaries, all streams entering and leaving the process, and points at which wastes are generated.

Boundaries should be selected according to the factors that are important for measuring the type and quantity of pollution prevented, the quality of the product, and the economics of the process. The amount of material input should equal the amount exiting, corrected for accumulation and creation or destruction.

A material balance should be calculated for each component entering and leaving the process. When chemical reactions take place in a system, there is an advantage to performing the material balance on the elements involved.

The limitations of material and energy balances should be understood. They are useful for organizing and extending pollution prevention data and should

be used whenever possible. However, the user should recognize that most balance diagrams will be incomplete, approximate, or both.

- Most processes have numerous process streams, many of which affect various environmental media.
- The exact composition of many streams is unknown and cannot be easily analyzed.
- Phase changes occur within the process, requiring multimedia analysis and correlation.
- Plant operations or product mix change frequently, so the material and energy flows cannot be accurately characterized by a single balance diagram.
- Many sites lack sufficient historical data to characterize all streams.

These are examples of the complexities that will recur in the analysis of real-world processes.

Despite the limitations, material balances are essential to organize data, identify gaps, and permit estimation of missing information. They can help calculate concentrations of waste constituents where quantitative composition data are limited. They are particularly useful if there are points in the production process where it is difficult or uneconomical to collect or analyze samples. Data collection problems, such as an inaccurate reading or an unmeasured release, can be revealed when "mass in" fails to equal "mass out." Such an imbalance can also indicate that fugitive emissions are occurring. For example, solvent evaporation from a parts cleaning tank can be estimated as the difference between solvent put into the tank and solvent removed by disposal, recycling, or dragout.

12.2.2 Define Pollution Prevention Options

Once the sources and nature of wastes generated have been described, the assessment team enters the creative phase. In a two-step procedure, they will propose and then screen pollution prevention options. Their objective is to generate a comprehensive set of options, ranked as to priority, that merits detailed feasibility assessment.

Propose Options. As with other planning efforts, the best results will be achieved in an environment that encourages creativity and independent thinking by each assessment team member. Brainstorming sessions are useful for encouraging creative thought because they provide a nonjudgmental, synergistic atmosphere in which ideas can be shared. Then, these ideas can be developed by means of group decision-making techniques. This approach will enable the assessment team to identify options that the individual members might not have come up with on their own.

Structuring option definition sessions according to the EPA pollution prevention hierarchy will encourage the team to look first at true source reduction options, such as improved operating procedures and changes in technology, materials, and products. Then, options that involve reuse, or closed-loop recycling, would be examined. The team would next consider off-line and off-site recycling and, finally, alternative treatment and disposal methods.

Screen Options. Many proposed options may result from the previous step. Since detailed technical, economic, and environmental feasibility analysis can be costly, the proposed options should be screened by the assessment team. Some options will be found to have no cost or risk attached; these can be implemented immediately. Others will be found to have marginal value or to be impractical; these will be dropped from further consideration. The remaining options will generally be found to require feasibility assessment.

This screening does not require detailed and costly study. Screening procedures can range from an informal review, with a decision made by either the program manager or a vote of the team members, to the use of quantitative decision-making tools. Figure 12-7 shows questions to be considered in option screening.

The informal review is a procedure by which the assessment team selects the options that appear best after discussing and examining each option. As is the case when the team is proposing options, its approach to screening should employ group decision-making techniques whenever possible.

In more complicated situations, the team may need to use a formal decision analysis technique designed for use in complex decision-making situations.

Questions for Option Screening

- Which options will best achieve the goal of waste reduction?
- What are the main benefits to be gained by implementing this option (financial, compliance, liability, workplace safety, etc.)?
- Does the necessary technology exist to develop the option?
- How much does it cost? Does it appear to be cost-effective, meriting in-depth economic feasibility assessment?
- Can the option be implemented within an reasonable amount of time without disruptions in production?
- Does the option have a good track record? If not, is there convincing evidence that the option will work as required?
- What other areas will be affected?

Figure 12-7. Considerations for option screening.

12.2.3 Feasibility Analyses

The final product of the option definition phase is a prioritized list of pollution prevention options. These options now should be examined to determine which are technically, environmentally, and economically feasible and to prioritize them for implementation.

Depending on the resources currently available, it may be necessary to postpone feasibility assessments for some options. However, all options should be evaluated eventually.

Technical Evaluation. The assessment team will perform a technical evaluation to determine whether a proposed pollution prevention option is likely to work in a specific application. Technical evaluation for a given option may be relatively quick or it may require extensive investigation. The list in Fig. 12-8 suggests some criteria that could be used in a technical evaluation. Some of these are more detailed versions of questions asked during the option screening phase.

All groups in the facility that will be affected directly if the option is adopted should contribute to the technical evaluation. This might include people from production, maintenance, QC/QA, and purchasing. In some cases, customers may need to be consulted and their requirements verified. Prior consultation and review with these groups will ensure the viability and acceptance of an

Typical Technical Evaluation Criteria

- Will it reduce waste?
- Is the system safe for our workers?
- Will our product quality be improved or maintained?
- Do we have space available in our facility?
- Are the new equipment, materials, or procedures compatible with our production operating procedures, work flow, and production rates?
- Will we need to hire additional labor to implement the option?
- Will we need to train or hire personnel with special expertise to operate or maintain the new system?
- Do we have the utilities needed to run the equipment? Or must they be installed at increased capital cost?
- How long will production be stopped during system installation?
- Will the vendor provide acceptable service?
- Will the system create other environmental problems?

Figure 12-8. Typical technical evaluation criteria.

option. If the option calls for a change in production methods or input materials, carefully assess the likely effects on the quality of the final product. If, after the technical evaluation, the option appears impractical or can be expected to lower product quality, drop it.

For options that do not involve a significant capital expenditure, the team can use a "fast-track" approach. For example, procedural or housekeeping changes can often be implemented quickly, after the appropriate review, approvals, and training have been accomplished. Material substitutions also can be accomplished relatively quickly if there are no major production rate, product quality, or equipment changes involved.

Equipment-related options or process changes are more expensive and may affect production rate or product quality. Therefore, such options require more study. The assessment team will want to determine whether the option will perform in the field under conditions similar to the planned application. In some cases, they can arrange, through equipment vendors and industry contacts, visits to existing installations. Experienced operators' comments are especially important and should be compared with vendors' claims. A bench-scale or pilot-scale demonstration may be needed. It may also be possible to obtain scale-up data using a rental test unit for bench-scale or pilot-scale experiments. Some vendors will install equipment on a trial basis, with acceptance and payment after a prescribed time, if the user is satisfied.

Environmental Evaluation. In this step, the detailed assessment team will weigh the advantages and disadvantages of each option with regard to the environment. Often the environmental advantage is obvious—the toxicity of a wastestream will be reduced without generating a new wastestream. Most housekeeping and direct efficiency improvements have this advantage. With such options, the environmental situation in the company improves without new environmental problems arising.

Unfortunately, the environmental evaluation is not always so clearcut. Some options require a thorough environmental evaluation, especially if they involve product or process changes or the substitution of raw materials.

For example, the engine rebuilding industry is dropping solvent and alkaline cleaners to remove grease and dirt from engines prior to disassembly. Instead, they are using high-temperature baking followed by shot blasting. This shift eliminates waste cleaner but presents a risk of atmospheric release because small quantities of components from the grease can vaporize.

To make a sound evaluation, the team should gather information on the environmental aspects of the relevant product, raw material, or constituent part of the process. This information would consider the environmental effects not only of the production phase and product life cycle but also of extracting and transporting the alternative raw materials and of treating any unavoidable waste.

Energy consumption should also be considered. To make a sound choice, the evaluation should consider the entire life cycle of both the product and the production process.

Economic Evaluation. Estimating the costs and benefits of some proposed pollution prevention projects is straightforward, while others prove to be complex. Despite the ease with which the cost calculations may be done for some options, it is advisable to document all that are adopted and to estimate the economic effects of each. This will help ensure that these real accomplishments of your pollution prevention program will not be overlooked when you measure the program's progress, as discussed in Chap. 16.

There are a number of factors that make pollution prevention costs and benefits difficult to calculate for many proposed projects. The total costs of continuing to pollute are not discernible in most corporate accounting systems. Furthermore, many of these costs are probabilistic—although the risks are real, it is difficult to predict the cost and even the occurrence date from past experience. The long-term need to avoid the spiraling costs of waste treatment, storage, and disposal, as well as future regulatory and liability entanglements, are likely to be major elements of your pollution prevention project economic evaluation.

Chapter 16 discusses an approach and gives an overview of the types of cost and benefit factors that should be examined when proposed pollution prevention projects are studied. It suggests some approaches to calculating indirect and probabilistic costs so that their full impact can be included in economic feasibility assessments. It also discusses ways to track the economic effects of pollution prevention projects after they are implemented.

12.2.4 Assessment Report

The task force should write a report that summarizes the results of the detailed pollution prevention assessments. The minimum contents are summarized in Fig. 12-9. The report will provide a schedule for implementing prevention projects and will be the basis for evaluating and maintaining the pollution prevention program. It may also be needed to secure internal funding for projects that

Discussion Points for Each Proposed Project Report

- Its pollution prevention potential
- The maturity of the technology and a discussion of successful applications
- The overall project economics
- The required resources and how they will be obtained
- The estimated time for installation and start-up
- Possible performance measures to allow the project to be evaluated after it is implemented

Figure 12-9. Contents of an assessment report.

require capital investment, if the members of the pollution prevention assessment task force do not have the authority to commit funds.

It may be tempting to omit this step if the company has an owner-manager and only a few employees. A summary assessment report may not be needed to resolve pollution prevention project conflicts among different areas, and funding approvals probably are not a formal procedure requiring cost justifications. However, an assessment report will help focus subsequent pollution prevention efforts and will be useful as a record of what aspects of the business have been examined for pollution prevention opportunities.

Input of the Assessment Teams. In a company that has several assessment teams, the task force will need to evaluate the results and resolve any conflicts that might exist among the teams as to approach and resources required for the projects proposed.

As input to this integration effort, each assessment team should prepare a summary report, presenting the results of its investigations and listing the options it screened. Each report should describe in some detail the options that the team has determined are feasible and propose a schedule for implementing them. The options recommended for immediate implementation should then be described in detail as proposed projects.

These proposals should evaluate each project under different scenarios. For example, the profitability of each could be estimated under both optimistic and pessimistic assumptions. Where appropriate, sensitivity analyses indicating the effect of key variables on profitability should be included. Each should outline a plan for adjusting and fine-tuning the initial projects as knowledge and experience increase. The proposals should include a schedule for addressing those areas and wastestreams with lower priorities than the ones selected for the initial effort.

Preparing and Reviewing the Assessment Report. The task force will use the assessment teams' reports and project proposals to prepare the summary assessment report and implementation plan. The report should include a qualitative evaluation of the indirect and intangible costs and benefits of a pollution prevention plan to the company, its employees, and the community. It will provide the basis for obtaining funding of pollution prevention projects. Pollution prevention projects should not be sold on their technical merits alone; a clear description of both tangible and intangible benefits can help a proposed project obtain funding.

Before the report is issued in final form, managers and other experienced people in the production units that will be affected by the proposed projects should be asked to review the report. Their review will help to ensure that the projects proposed are well defined and feasible from their perspectives. While they probably were involved in the site reviews and other early efforts of the task force, they may spot inaccuracies or misunderstandings on the part of the assessment teams that were not apparent before.

In addition to ensuring the quality of the assessment report and implementation plan, this review will help ensure the support of the people who will be responsible for the success of the project.

12.2.5 Implement the Pollution Prevention Plan

Select Projects for Implementation. Final decisions on which projects will be implemented and what the schedule will be are made at this point. If the task force or company executives question aspects of some projects, the assessment teams or pollution prevention program champions may be asked to produce additional data. The task force should be flexible enough to develop alternatives or modifications. The members should also be willing to do background and support work, and they should anticipate potential problems in implementing the options. Above all, they should keep in mind that an idea will not sell if the marketers are not convinced.

Obtain Funding. The task force will seek to secure funding for those projects that will require expenditures. There will probably be other projects, such as expanding production capacity or moving into new product lines, that will compete with the pollution prevention program for funding. If the task force is part of the overall budget decision-making procedure, it can make an informed decision that a given pollution prevention project should be implemented right away or that it can wait until the next capital budgeting period. The task force will need to ensure that the project is reconsidered at that time.

Some companies will have difficulty raising funds internally for capital investment. If this applies, look to outside financing. Private sector financing includes bank loans and other conventional sources of financing. Financial institutions are becoming more cognizant of the sound business aspects of pollution prevention.

Government financing is available in some cases. It may be worthwhile to contact your state's department of commerce or the U.S. Small Business Administration for information regarding loans for pollution control. Some states can provide financial assistance.

Install the Selected Projects. Many pollution prevention projects will require changes in operating procedures, purchasing methods, or materials inventory control. Company policies and procedures documents and employee training will also be affected by the changes.

For projects that involve equipment modification or new equipment, the installation of a pollution prevention project is essentially the same as any other capital improvement project. The phases of the project include planning, design, procurement, construction, and operator training. As with other equipment acquisitions, it is important to get warranties from vendors prior to installation of the equipment.

Training and incentive programs may be needed to get employees used to the new pollution prevention procedures and equipment.

Measure Progress Against the Goals. By reviewing the program's successes and failures, managers at all levels can assess the degree to which pollution prevention goals at the facility and production unit levels are being met and what the economic results have been. The comparison identifies pollution prevention techniques that work well and those that do not. This information will help guide future pollution prevention assessment and implementation cycles.

Quantitative evaluation also enables comparison with similar units in the company and with data from other companies. This knowledge is needed to plan enhancements to the current pollution prevention program, to select technologies for transfer from other operations, and to help identify new pollution prevention options.

Review and Adjust. The pollution prevention process does not end with implementation. After the pollution prevention plan is implemented, track its effectiveness versus the claims made—technical, economic, etc. Options that do not meet your original performance expectations may require rework or modifications. Above all, reuse the knowledge gained by continuing to evaluate and fine-tune pollution prevention projects. Chapter 17 provides details on measuring progress after implementation and evaluating it against goals. Chapter 8 deals with ways to maintain and enhance a program after it is implemented.

IDENTIFYING POLLUTION PREVENTION OPTIONS

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APPENDIX III. NOTATION

The following symbols are used in this paper:

a = volumetric air content of soil (dimensionless);
b = coefficient (g/g);
$\bar{C}_{air}$ = average contaminant concentration in air (g/cm³);
C_g = contaminant concentration in soil gas phase (g/cm³);
C_g^* = maximum contaminant concentration in soil vapor phase (g/cm³);
C_l^* = maximum contaminant concentration in soil pore water (g/cm³);
C_{ai} = initial contaminant concentration adsorbed to soil (g/g);
C_{ae} = concentration adsorbed to soil in equilibrium with C_g^* (g/g);
C_t = total contaminant concentration in soil (g/cm³);
$\bar{C}_a$ = average contaminant concentration adsorbed to soil (g/g);
ADD = lifetime average daily absorbed dose (mg/kg/day);
D_e = effective diffusion coefficient (cm²/s);
D_g = soil-gas diffusion coefficient (cm²/s);
D_l = soil-liquid diffusion coefficient (cm²/s);
K_d = equilibrium soil-water partition coefficient (cm³/g);
K_{oc} = equilibrium partition coefficient normalized to organic carbon (cm³/g);
$\bar{Q}$ = average emission rate of contaminant from soil surface (g/s);
T = averaging time variable (s);
t = time (s);
T^* = averaging time variable (s);
z = depth below soil surface (cm);
ϵ = dimensionless coefficient; and
ρ_b = bulk density of soil (g/cm³).

Identifying Promising Pollution-Prevention Technologies

By James D. Englehardt,[1] Associate Member, ASCE

Abstract: The majority of hazardous waste is generated industrially, and the importance of industrial pollution prevention to economic and environmental sustainability is now recognized. Sustainability can be evaluated using benefit-risk analysis, globally and locally by public agencies and firms. To evaluate pollution prevention seriously, using benefit-risk analysis or other methods, the benefits of hazardous materials use in industry must be recognized. Pollution-prevention technologies in a broad range of industries were reviewed as a part of research to develop benefit-risk methods. Ten basic functions served by hazardous materials in industry were identified as binding, pigmentation, reactants, reaction inhibition, catalysis, bleaching, mass deposition, mass removal, by-products, and end products. Pollution prevention technologies were associated with each function. The classification of technologies offers a basis for development of general pollution-prevention approaches, and promotes transfer of technologies among industries in which hazardous materials perform similar functions. Hazardous materials used for mass transfer, and those generated as by products, appear to represent areas of opportunity for pollution prevention research and development.

INTRODUCTION

Increasing process efficiencies by minimizing the waste of valuable materials is a long-held objective of engineering design of industrial processes. However, most hazardous waste is generated industrially. Recently, the social cost of waste, particularly hazardous waste, has been recognized, and costs have been assigned to generators through legislation. Therefore, pollution prevention is an essential component of industrial process design.

By the laws of thermodynamics, all productivity is accompanied by waste. That is, only when productivity is zero is waste ultimately minimized. Therefore, to discuss pollution prevention seriously, industrial productivity must be considered simultaneously with waste generation. Productivity and waste can be measured in units of energy or mass. However, a more motivating scale of measurement, with respect to selection and design industrial processes that are sustainable both economically and environmentally, may be monetary.

A useful framework for evaluating and selecting pollution prevention proposals, considering production together with waste generation, is that of benefit-risk analysis. Such an analysis can be conducted from the perspective of the public or of the firm, and on a local or process scale, or a global or regional level. If performed from the perspective of the firm, a useful concept may be the perception of hazardous waste as a product with negative market value (Cranford, unpublished remarks, 1993). In fact, pollution prevention is now recognized as an essential component of total quality management (Isbell 1991; Alm 1992). Because perceived production benefits and costs are considered in an integrated way in benefit-risk anal-

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Note. Discussion open until November 1, 1994. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on June 25, 1992. This paper is part of the ***Journal of Environmental Engineering***, Vol. 120, No. 3, May/June, 1994. ©ASCE, ISSN 0733-9372/94/0003-0513/$2.00 + $.25 per page. Paper No. 4291.

ysis, the approach may be effective in stemming the accumulation of hazardous wastes in the face of population and technological pressures, and in maintaining economic and environmental sustainability.

If performed from the point of view of the firm, benefit-risk analysis of pollution prevention alternatives requires explicit recognition of the beneficial functions served by industrial hazardous materials, as well as the environmental and health risks and liabilities. Such recognition of the functions served by hazardous materials in industrial processes further allows: (1) Transfer of successful pollution prevention technologies among different industries where hazardous materials perform essentially similar functions; and (2) research and development of general approaches to pollution prevention.

Identification of technical alternatives is the first step in conducting a benefit-cost analysis, to minimize waste associated with a production process. Industries generate solid, liquid, and gaseous hazardous waste materials in virtually unlimited, and highly site-specific, ways. Therefore, identification of pollution prevention strategies can be challenging, especially for proposed new production processes, and in light of uncertain environmental and health liabilities. A preliminary list of alternative pollution prevention alternatives for a process can be developed by literature review. A broad review allows identification of waste minimization strategies at the corporate and regional level, as well. For example, possible uses of waste from one production facility in another, unrelated, facility may be found.

Technologies reported for reducing hazardous wastes in a broad range of industries were reviewed (Englehardt 1993), in the course of research to develop pollution prevention benefit-risk analysis methods (Englehardt 1991). The objective of the literature review was to provide an overview of current approaches to industrial pollution prevention, broad with respect to industry, and integrated in outlook. That is, it was desired to provide a way of thinking about pollution prevention that transcended commonly recognized, site-specific technologies; a multimedia view, considering production advantages and risks, and broad enough to allow planning at the corporate and regional levels, was desired. Radioactive, infectious, and nonhazardous wastes were not considered, although pollution prevention opportunities for such materials may be interrelated with those of the hazardous wastes discussed.

In the course of the literature review, ten functions served by hazardous materials in industry were identified. Literature information was reorganized according to these functions, as a basis for development of general pollution prevention strategies. In this paper, the organization of current pollution prevention information in the literature, and several generally recognized waste minimization techniques, are reviewed. The proposed conceptual organization of technologies, in terms of beneficial functions and risks of hazardous materials, is then discussed, with a brief example application. Conclusions offer insight into pollution prevention opportunities, and future research directions.

WASTE-REDUCTION LITERATURE

Many good studies on pollution prevention technologies were reviewed. Three main classification systems were found, all of which have advantages. Technologies have most often been reviewed by industry group, such as metal finishing, photographic processing, or industrial solvent uses (Campbell and Glenn 1982; Higgins 1989; Kafarov 1985; Tavlarides 1985, United

Nations, no year; *Solvent* 1990; *Hazardous* 1989). Such a perspective is useful for analysis of industrial processes as they exist at the time, due to the site-specific nature of industrial waste technologies. However, process-specific material can become dated, and waste-minimization opportunities resulting because one firm owns several types of industrial operations are not considered. For example, an opportunity to detoxify and reuse ash or other silica waste from one industrial process as raw material in cement kilns or glass furnaces in another process, would not be addressed.

Waste reduction technologies have also been reviewed by unit process, such as distillation or filtration (Noll et al. 1985; "Alternative" 1986, Munroe et al. 1990). Because of their generality, such reviews are lasting. However, without considering production output explicitly, waste treatment rather than waste reduction may be suggested, and many site-specific waste minimization opportunities cannot be addressed.

Other process descriptions are specific to the phase of the waste, solid, liquid, or gas [e.g., Hagler (1988)]. This organization incorporates advantages of the previous two systems, but transfer of waste between phases may be inadvertently encouraged. A benefit-risk perspective was desired

WASTE-MINIMIZATION METHODS

Several basic methods of reducing hazardous wastes are often identified, more or less following Campbell and Glenn (1982). Methods are described here approximately in order of preference.

Substitution of less hazardous or higher yield raw materials and processing agents is a basic consideration in developing alternatives for sustainable production. Reformulation by the supplier to eliminate hazardous contaminants may be included. Even where the end product is a hazardous material, foresight may suggest investigation of nonhazardous substitutes.

Alternative processing, meaning some change in the design of the process, may eliminate the need for the use of hazardous materials, particularly processing agents, reduce waste generation, or improve process efficiency (thus minimizing waste).

Loss reduction involves improving the efficiency of converting raw material to product, of utilizing processing agents, and of recovering product, so that materials are lost in smaller quantities. The most effective single approach to accomplishing such increases in efficiency is to track hazardous materials so as to maintain accountability, and institute an accounting system assigning actual costs to responsible production units. Improvements in plant design, operation, and/or maintenance can reduce chronic leakage and other losses. Improving plant organization and operation can result in fewer accidental losses, for example, by instituting spill prevention programs and improving material handling and storage procedures.

Automated and/or computerized process control has been found in many applications to reduce emissions and other losses, and improve yields. For example, production runs may be scheduled so as to minimize cleanout of different materials from equipment. Automating mineral refining processes may increase efficiency of ore conversion and reduce production of reject material.

Reuse of hazardous materials, unavoidably lost from the process, without further processing, is often possible. Reuse may be in the same process, or in another. Equipment can be installed to return lost material to the process. Materials not reusable in the same process may be reused in a less sensitive application, resold or exchanged externally, or incinerated for energy re-

covery. Reuse of by-products as raw materials (especially for building materials), as neutralizing agents for other wastes, or as fuel for incineration in industrial boilers is becoming common.

Recovery is the purification or reclamation of a contaminated material for reuse, or the recovery of a usable hazardous contaminant (such as a metal) from a waste stream for reuse or resale. In the production of hazardous materials, product can be recovered from waste streams, and off-specification or outdated material can be chemically upgraded. Recovery of metals, organics, etc. from by-products, or catalytic or other chemical conversion of by-product to useful material is appropriate where direct reuse without further processing is not possible.

Specialization refers to the purchase, use, and production of a minimum number of hazardous materials, and the dedication of equipment to specific hazardous materials or products. Restricting the purchase and use of a minimum of hazardous processing agents, such as solvents, facilitates other waste reduction measures including segregation, recovery, reuse, and disposal. Dedicating equipment to the use or production of specific hazardous materials minimizes cleanout requirements and associated waste.

Tracking and labeling of hazardous materials is effective in reducing the usage and loss of material. Maintaining accountability for the use, generation, and disposal of hazardous materials is essential for minimizing waste. Incentives must be instituted by management.

Segregation of wastes, or collecting, storing, and disposing of different types separately, facilitates reuse and recovery, and improves the efficiency of waste treatment and disposal.

Detoxification of wastes prior to disposal is the last alternative, prior to simple treatment and discharge. Detoxification can be accomplished biologically, chemically, as by neutralization or chemical stabilization, thermally, as by incineration or pyrolysis, or physically, as by fixation or solidification. Thus, risks associated with otherwise unavoidable wastes may be minimized.

Dilution is a common method of detoxifying hazardous waste legally, as well as toxicologically, and can thus be considered a waste minimization method. However, the quantity of hazardous contaminant is not actually reduced. Measures often loosely referred to as "good housekeeping" include using a minimum number of different chemicals (specialization), labeling and tracking materials, segregating wastes, maximizing material recovery, and maintaining equipment to reduce losses.

FUNCTIONS OF HAZARDOUS MATERIALS

Industrial wastes arise in many ways, and are associated with various direct and indirect benefits and costs. Wastes arise from process inefficiencies and from final disposal of finished products. For example, petroleum drilling operations generate leachable drilling muds (a by-product), the oil refining process subsequently generates various waste hydrocarbons in producing solvents, fuels, and asphalt products (an example of process inefficiencies), and the ultimate consumer of a product such as motor oil discards the product after use (a postconsumer waste). Postconsumer wastes are not considered here.

Industrial wastes, whether hazardous or not, are generated as losses of raw materials, processing agents, intermediates and byproducts, and end products (Overcash 1986), as depicted in Fig. 1. Hazardous raw materials

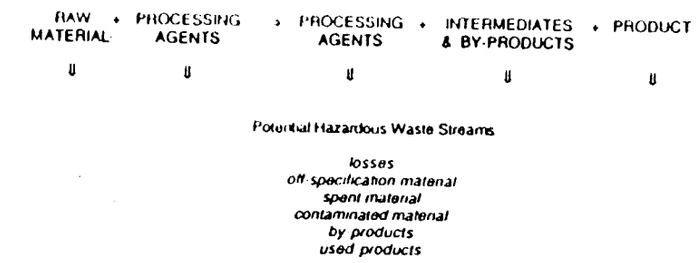

FIG. 1. Sources of Hazardous Waste in Industrial Processes

include binders, reactants, pigments, and bleaches. Material losses result from contamination, leakage, volatilization, process inefficiencies, and accidents. Processing agents, or materials not incorporated in the final product, include organic solvent carriers for coatings, inks, and dyes, cyanide metal plating baths, organic and caustic cleaners, acid etchants and cleaners for metal, and catalysts. With the exception of catalysts, which enhance reaction rates and thereby reduce waste relative to production rates, such materials are used to only to convey material. Therefore, hazardous processing agents, although representing one of the largest uses of hazardous material, are often not necessary to the process. Industrial wastes differing chemically from beneficial process materials are grouped as by-products. Such materials include stack gases, and mine tailings and drainage water. Hazardous end products, a final broad group of industrial hazardous materials, include organic and inorganic chemicals, solvents, pharmaceuticals, pesticides, and metal pigments. Industries in which hazardous materials are used or generated are summarized in Table 1 (Englehardt 1993), according to material function.

Ten fundamental functions served by hazardous materials industrially were identified, in the course of the literature review on pollution prevention technologies. These functions represent the essential benefits of hazardous material use. Associated environmental and health risks, and resulting liabilities, are represented by the chemical nature of the material. Four general chemical classes were recognized as organics, metals, oxidation-reduction reactants (such as cyanide), and acid-bases. Basic approaches to pollution prevention for each functional type were reviewed, with an eye for similarities among technologies reported where hazardous materials perform the same underlying function in different industries.

The following rudimentary functions of industrial hazardous materials may be recognized

- Binding (organics)
- Pigmentation (metals)
- Reactants (organics, acid-bases, oxidants-reductants, and metals)
- Reaction inhibition (metals and organics)
- Catalysis (metals)
- Bleaching (oxidants)
- Mass removal (organics and acid-bases)
- Mass deposition (organics, acid-bases, and oxidants-reductants)
- By-products (organics, metals, acid-bases, and oxidants-reductants)

TABLE 1. Industrial Hazardous Waste Generators, Grouped by Hazardous Material Function

Function of material (1)	Hazardous waste generator (2)
Binding	Wood and building products
Pigmentation	Coating (e.g., paint, lacquer); furniture, motor vehicles, aircraft, appliances, metal and wood products manufacturing
	Textiles
	Printing
Reactants	
Metal	Organic chemicals manufacture (biocides, pharmaceuticals, solvents, resins)
	Inorganic chemicals
	Metal refining
	Tanning
	Photographic processing
Oxidation-reduction	Pulp and paper
	Metal refining
Acid-base	Chemical manufacturing
Reaction inhibition	Chemical manufacturing
	Metal finishing
	Refining
	Building products
Bleaching	Pulp and paper
	Textiles
Mass deposition	
Organic	Coating (e.g., paint, lacquer); manufacture of metal, wood, and other products
	Printing
	Organic chemicals; manufacture of solvents, resins, pesticides, pharmaceuticals
Oxidation-reduction	Electrolytic metal plating and stripping; automotive, aircraft, electronics, semiconductors, pickled steel, foundries and other metal manufacturing
Mass removal	
Organic	Cleaning, degreasing, and rinsing; vehicle maintenance, manufacture of aircraft, motor vehicles, metal furniture, tools, appliances, paint, ink, organic and agricultural chemicals, adhesives, petrochemical, plastics, rubber, vegetable oil, textiles, semiconductors, and other products, photographic processing, coating, printing, and other industries
	Paint stripping
	Dry cleaning
Acid-base	Metal stripping; automotive, aircraft, electronics, pickled steel, metal furniture, foundries and other metal manufacturing
	Metal etching
	Metal refining
By products	
Organic	Petroleum refining
	Automotive and industrial lubrication
	Solvent reclamation

TABLE 1. (*Continued*)

(1)	(2)
Metal	Mining
	Metal refining
	Waste incineration
	Foundries
Oxidation-reduction and acid-base	Metal refining
	Petroleum refining
	Inorganic chemicals manufacturing
	Organic chemicals manufacturing
	Power production
End products	Organic chemicals: manufacture of solvents, resins, pharmaceuticals, biocides
	Metal pigment manufacture
	Manufacture of inorganic acids, bases

- End products (organics, acid-bases, oxidants-reductants, and metals)

The functions are discussed below, along with general pollution prevention opportunities. An effort to summarize the relative importance of various pollution prevention approaches to industrial processes associated with each function is presented in Table 2 (Englehardt 1993).

Binding

Organic binders are used in the manufacture of building materials, including plywood, fiberglass insulation, and composite boards. Binders include phenolic resins and formaldehyde, as well as certain wood preservatives and flame retardants such as creosote, which perform essentially a binding function. Material losses represent hazardous wastes. If substitution is not possible, waste can be reduced by minimizing the number of different hazardous materials purchased and used, and tracking material to maintain accountability. Installation of drip return equipment, and recycling of cooling water, have reduced waste. Specialization, by dedication of equipment, reduces cleanout waste and allows in-process recycling. Binder wastes can be recovered, as, for example, by evaporation. Volatile resins may be absorbed in aqueous solution, evaporated, and condensed. Sizing chemicals for fibers may be recovered by ultrafiltration.

Pigmentation

Metals are used as pigments in paint and other coatings used to manufacture wood and metal furniture, vehicles, and appliances, in dyes for paper and textile products, and in inks for printing paper, and glass and metal food and beverage containers. Metals used include titanium dioxide, lead, cadmium, and hexavalent chromium. Typically, solvent carriers may represent more of the toxicity present in wastes. However, metals further complicate disposal problems. Pollution prevention opportunities include the marketing of natural colored products in light of heightened consumer awareness, and the use of less hazardous organic pigments. Computer scheduling of operations so as to dedicate particular equipment to particular products, thereby minimizing equipment cleanout requirements, is good operating practice. Automated process control may reduce process losses.

TABLE 2. Ranking of Pollution Prevention Technologies by Industrial Hazardous Material Function

Method (1)	Binding (2)	Pigmentation (3)	Reactants (4)	Reaction inhibition (5)	Catalysis (6)	Bleaches (7)	Mass deposition (8)	Mass removal (9)	By-products (10)	End products (11)
Substitution	5	3	3	3	1	4	5	5	1	3
Alternative process	1	5	3	1	1	1	5	5	5	2
Loss reduction	5	5	5	5	1	5	5	5	1	4
Process control	5	5	5	3	1	4	5	4	5	5
Reuse	2	3	4	1	5	1	2	4	5	1
Recovery	3	5	5	2	5	5	4	5	5	4
Specialization	2	2	2	2	1	1	5	4	1	4
Tracking	4	1	3	4	1	2	1	4	1	2
Segregation	2	1	2	2	2	1	2	4	2	1
Detoxification	1	2	2	1	2	2	3	1	3	1

Note: 5 = most important; 1 = least important

Reactants

Chemical reactants include metals, acids and bases, oxidizing and reducing agents, and organics, such as sacrificial metal electrodes, vinyl chloride monomer, caustic and reducing chemicals used to make wood pulp, acids, bases, organics, and other raw materials and intermediates in organic and inorganic chemicals production, chromium tannins for leather, photographic developing chemicals, and fluoride fluxes used to lower the melting point of silica materials. Material losses via contamination, leakage, production of off specification material, volatilization, and desired reactions, represent hazardous waste sources. Loss reduction, process control, and recovery measures may be appropriate. Many gaseous and liquid forms of common acids, input and output from chemical reactions, can be recovered and recycled electrolytically, catalytically, by oxidation, and by absorption. Silver can be recovered from photographic film scraps, fix solutions, and washwaters electrolytically or by ion exchange or precipitation. Where other sodium or boron salts cannot be substituted for fluoride flux in silica processing, fluorides are precipitated with lime.

Reaction Inhibition

Various organic, metallic, alkaline, and antioxidant chemicals are used to inhibit corrosion, oxidation, chemical degradation, or biological activity in processing agents and end products. Examples include cooling water additives in chemical manufacturing and metals and petroleum refining, organic and metallic wood preservatives and flame retardants, and metal plating bath additives. Inhibitors added to organic cleaning solvents include antioxidants, to suppress oxidation of unsaturated solvents, metal stabilizers, to react with metal contaminants that accelerate solvent degradation, and alkaline organics, that absorb hydrochloric acid produced in the breakdown of chlorinated solvents, thereby inhibiting solvent breakdown and corrosion of equipment and parts being cleaned (Higgins 1989). Losses result from not recycling process waters, from changing process waters due to contamination, from leakage and accidents, in rinsing steps, and in process water recovery processes. In general, substitution of less toxic inhibitors is desirable for long term economic sustainability. It may be possible to reduce losses by recovering additives together with metal plating bath solution, by distillation, adsorption, or membrane processes.

Catalysis

Catalysts are used to enhance chemical reaction rates in the refining of petroleum and inorganic minerals, in the manufacture of organic chemicals such as pharmaceuticals and inorganic chemicals, and in food processing. Catalysts are most often metals, inert in the reaction, such as platinum, nickel, zinc, cobalt, vanadium, molybdenum, iron oxides, and chromium, sometimes deposited on alumina. For example, powdered nickel catalyzes hydrogenation of vegetable oil, and nickel, iron-chrome alloys, or copper-zinc alloys catalyze steam and thermal generation of hydrogen from hydrocarbons.

Catalyst activity is reduced by permanent or reversible fouling or poisoning with contaminants. Spent catalysts can be a significant source of toxic metallic waste in chemicals manufacturing, although regeneration is practiced widely due to costs of material purchase and disposal. Spent catalysts can be regenerated by solvent stripping, heat treatment, acid washing, or gaseous oxidation or reduction. When the catalyst is finally spent, metal

may be recovered from wastes by electrolysis, ion exchange, precipitation, and many other processes.

Bleaching

Chlorine and oxygen bleaches are used in the manufacture of white paper and textiles. Photographic processing operations use permanganate, ferricyanide, and dichromate bleaches, of which ferricyanide is of concern due to the potential for decomposition to free cyanide in the presence of sunlight. Chlorine reacts with organics to form trihalomethanes in receiving waters. Substitution and recovery are demonstrated pollution prevention approaches. Consumer awareness is increasing the marketability of nonwhite paper products. Oxygen bleach can be substituted for chlorine. Process waters can be recycled, and countercurrent rinsing reduces losses. Computerized process control measures often reduce losses, as well. Ferricyanide bleach solutions used in photographic processing can be recovered by chemical or electrolytic oxidation (Campbell and Glenn 1982).

Mass Deposition

One of the most common functions of hazardous materials is that of mass deposition. Organic solvents and cyanide metal baths may be considered to be carriers, used as carriers of coatings, inks, dyes, chemicals, and metals. Solvents are used as thinners for paints, other coatings, and inks, and as media for reactions and extractions in organic chemicals manufacturing. Losses of volatile carriers are in some measure inherent to their use, as they are often used because of their evaporative characteristics. Carriers do not become part of the finished product, and may not be essential for depositing material. Therefore, alternative methods of applying coating, ink, or chemicals, such as by heat or water, are suggested for preventing pollution. Aqueous formulations are finding application. Alternative processes under development for application of coatings include heat fusing of powdered coatings, dipping methods, and radiation curing of paint or ink. Losses can be reduced in many ways. In particular, computerized process control has been effective. Solvents are recovered by distillation, and incinerated for energy recovery.

Cyanide metal baths are used in electrolytic plating and stripping operations. Metal plating baths are lost inherently in the rinsing step, and from changing baths due to contamination. Noncyanide baths are economical in certain applications. Alternative processes include gas-phase deposition of metals, and spray application of heat-fused metals. Loss reduction measures include automated process control, minimization of "dragout" of solution on plated parts, and countercurrent rinsing systems, and are well reported. Metals can be recovered by electrolytic deposition, membrane separation, ion exchange, and precipitation, along with sedimentation, flotation, filtration, magnetic separation, extraction, and other methods. Cyanide can be oxidized chemically.

Mass Removal

Mass removal is another common function of hazardous materials, often not essential to the process. Halogenated and nonhalogenated organic solvents, caustic, and acids are used as cleaners, strippers, and etchants. Organic solvents are used in vehicle maintenance, painting, paint stripping, printing, dry cleaning, and in the manufacture of organic chemicals (pharmaceuticals, biocides, industrial materials), printed circuit boards, paint,

ink, and vegetable oil. However, often either: (1) Abrasives; or (2) aqueous cleaners are as effective, and elimination of solvent cleaners and strippers has resulted in substantially improved economics (Higgins 1989, *Guide* 1986). For example, blasting with plastic or other media is replacing the use of solvents for removing (stripping) paint in aircraft maintenance applications. Loss reduction measures include installation of covers and condensers, recovery by distillation, and specialization, all common practices. Economics generally favor on-site distillation over off-site commercial recycling, except for small operations. However, off-site recycling is more common. Spent solvents may be reused where some contamination is acceptable, or incinerated for energy recovery.

Alkaline cleaners are used for bottles, vehicle maintenance, and paint stripping. Acids are used to clean and etch metal surfaces. Losses commonly result from contamination. Recovery of acids and metal oxides by evaporative and precipitation methods is well established. For example, both hydrochloric acid and salable iron oxide are routinely recovered from spent hydrochloric acid steel pickling baths by roasting. Acids and bases can be used for neutralization of other wastes as well.

By-Products

Industrial hazardous materials that do not function as raw materials, reaction intermediates, processing agents, or end products, may be considered by-products. Losses of materials of value to the process, including raw materials, reaction intermediates, processing agents, and end products, are not considered by-products. Materials generated industrially, and not generally considered to be of value in the process, include stack gases, mine tailings, and recovery residues and sludges. Because most hazardous waste is released to the air, air-pollution prevention is expected to become a significant area of research.

Process modifications that increase efficiencies and reduce waste generation are first priorities. Maintaining accountability of production groups for discharges, and associated costs, reduces such discharges. Computerized process control is a generally appropriate alternative, particularly for larger operations. For example, crude-ore recovery rates can be improved by reducing production of reject material in mineral refining, through process control. Reuse and recovery of unavoidable residues are suggested in preference to detoxification and pretreatment measures. Opportunities for recovery are often limited only by the ability of process engineers to estimate process economics. Organic byproducts are considered catalytically, by distillation, separation, or other reforming process, or incinerated for energy recovery. Chlorinated organic residues can be incinerated, with HCl absorption from the flue gases in water. Alternatively, such residues have been converted to carbon tetrachloride and perchloroethylene by perchlorination with heat (*Waste* 1986; Simmler 1984). Liquid organics have been converted to ethylene by reaction with acetylene and heat (Simmler 1984). Acid can be recovered from flue gases (Hagler 1986) by absorption, adsorption, and catalytic processes. Flue gas can be used to neutralize other wastes directly, or contaminants can be precipitated. Particulates in air can be filtered or separated by cyclone. Recovery of waste heat in manufacturing and refining reduces stack gases from with power production. Metals can be recovered from mine tailings. Tailings or other mineral material from refining, power production, or waste incineration can be used as raw materials for building materials, or detoxified by stabilization. For example, metals may be re-

coverable from mineral refining wastes, or such material may be used in the manufacture of building materials.

End Products

Hazardous end products include acids and bases, biocides, pharmaceuticals, solvents, binders, and industrial reactants. Production losses, off-specification material, and outdated materials, represent sources of pollution. Pollution prevention opportunities differ from those in processes where the same materials are used as processing agents or raw materials. However, production of less hazardous substitutes is the first consideration for long term economic and environmental sustainability. As for other functions, computerized process control, and maintaining accountability for the costs of pollution, are high opportunity alternatives. Edgar and Himmelblau (1988) give mathematical programming methods for computer-aided optimization of chemical processes. Specialization, by dedication of equipment, allows in-process recycling and reduces equipment clean out requirements. Product losses can be reduced by sealing leaks, covering tanks, and condensing emissions. Recycling of cooling and other process waters, and heat recovery, reduce discharges. Products can be recovered by adsorbing, absorbing, decanting, centrifuging, and filtering.

EXAMPLE APPLICATION

Consider a hypothetical printing facility for printing metal food and beverage containers. Because solvent-based inks are used, several hazardous wastes are generated. Contaminated solvent used for equipment and product cleaning, volatile organic carbon air emissions from drying and other operations, dirty rags containing solvent residues and metal ink pigments, and ink residues are generated. Commonly such operations send contaminated solvents to a commercial recycler for distillation, to be returned for reuse. Risks of spillage in transit and of facility accidents are incurred. Cradle-to-grave liability may be substantial, although estimation of such liabilities is difficult.

In such processes the solvent is a nonessential processing agent, the solvent acting to deposit ink binder and pigments. From the previous discussion, solvent-based painting operations are recognized to use solvents in a similar way. Thus, technologies for minimizing wastes in the metal furniture industry, automotive painting, and appliance manufacturing industries may be considered in the printing application. Numerous references detailing applicable technologies are available (Campbell and Glenn 1982; Hazelwood and Burgher 1985; Higgins 1989; *Guide* 1986; *Hazardous* 1989; *Halogenated* 1990). For example, water-based inks may be appropriate. Heat application of powdered inks may be possible, and radiation cured inks have already been developed (Higgins 1989; Campbell and Glenn 1982). Computer scheduling of operations to minimize equipment cleanout requirements can reduce waste. The list of alternatives for the specific process under consideration can be refined further by literature search, and benefit-risk analysis can be used in selecting and designing final processes (Englehardt 1994).

CONCLUSIONS

From the industrial hazardous material functions identified, several observations can be made. First, catalysis, while sometimes generating metallic waste, accelerates reaction rates, thereby potentially reducing waste generation rates relative to productivity. Such uses may be consistent with pollution prevention goals. Regeneration (recovery) methods may prevent associated pollution.

Reactants, pigments, and binders are raw materials. Consideration of less hazardous materials or alternative processes may be justified, particularly where pigments and bleachers in single-use products, such as toilet paper, are not necessary. However, if such materials are nonhazardous in the end product, providing safe working conditions and reducing material losses may eliminate many of the associated risks. Where end products are hazardous, corporate strategic planning for sustainability should include evaluation of the production of alternative, less hazardous, products.

In the case of hazardous by-product generation, a change of thinking may be useful. That is, if by-products are thought of as other products, in terms of market value (negative for wastes), pollution prevention may occur more readily. A recognized motivating factor is implementation of accounting procedures that maintain accountability for all costs associated with pollutant discharge.

Hazardous processing agents are the source of much hazardous waste, and often are not essential to production. For example, abrasives and aqueous solvents have been found effective in conveying material in many applications. Coatings can be applied in radiation and chemically cured forms, with heat by dipping or spraying, or deposited in vapor form. Catalysts, which may be thought of as processing agents, are an exception because they generally increase the ratio of benefits to risks. Alternatives to the use of hazardous processing agents are expected to increase in importance, and their development is a promising area of research.

At the 1991 growth rate of 1.7% (*Statistical* 1992), the world population would double in 40 years. We may see a proportionate doubling of accumulated hazardous wastes in the environment unless sustainable production methods are developed. Recognition of the functions served by industrial hazardous materials may be useful to public agencies and firms in identifying global and local pollution prevention measures. Explicit recognition of such functions is a first step in conducting benefit-risk analyses, to select efficient pollution prevention and total productivity management approaches. Methods of estimating major uncertain costs, such as environmental and health liabilities, and production uncertainties associated with the use of wastes as raw materials, are being developed, to support selection of sustainable production technologies (Englehardt 1994; Englehardt and Lund 1992).

ACKNOWLEDGMENTS

The writer is grateful to the University of California Research and Teaching Program for support of this work, to the University of Miami Knight Junior Faculty Fellowship, which provided continued support, and to Drs. Jay Lund and George Tchobanoglous for their input and suggestions.

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Tests for Flow along Vertically Stratified Porous-Media Interfaces

By Ronald B. Manila Jr.[1] and J. Jeffrey Peirce[2]

Abstract: Two test methods were developed to detect preferential flow along the grout/clay interface in a cylindrical clay sample with a cementious grout core. One test detects preferential flow along the interface by taking ratios of the specific discharge in different regions of the specimen as measured with a triple-ring permeameter. The other test detects preferential flow along the interface by taking ratios of the velocity in different regions of the sample as measured by timing voltages changes as a sodium chloride solution passes through the sample. The results of both tests indicate that preferential flow does occur in the short term along the grout/clay interface. Comparing the velocity ratios to the specific discharge ratios, it is shown that small volumes of liquid travel rapidly along the interface. While the tests lend insight into the mechanisms of preferential flow, caution must be used in applying the results of such laboratory scale specimens to the field situations. Changes to the equipment and procedures for future testing are suggested to improve reproducibility.

INTRODUCTION AND OBJECTIVES

In studying flow through natural and man-made porous media, there are applications that require the understanding of flow along an interface in stratified media. In this paper, a stratified medium is defined as any collection of porous materials in which the individual materials exist in distinct sections or layers.

A field example of a vertically stratified medium is a grouted borehole. The structure of such a borehole was the impetus to the development of the test procedures presented in this paper. A vertical cross section of a grouted borehole and the surrounding soil are shown in Fig. 1. Since the interface between the grout and the soil presents a potential path for vertical preferential flow, it is important to understand how this interface behaves. If a borehole passes through an otherwise continuous aquitard, such vertical preferential flow could provide a pathway for cross-contamination from a contaminated to an uncontaminated aquifer. Minor cross-contamination could lead to false positive measurements from samples in the uncontaminated aquifer. More substantial cross-contamination could occur if the head difference between the aquifers is increased by active pumps near the borehole.

The goal of this paper is to present the methods and results of two tests developed to detect preferential flow along the interface of a vertically stratified medium composed of cementitious material and field clay. Only initial flow trends are examined rather than long-term equilibrium conditions. The specific objectives of this paper are: (1) To summarize the development and procedures of the two tests performed; (2) to show whether preferential flow is indicated along the interface of the test specimens during

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Note. Discussion open until November 1, 1994. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on March 24, 1992. This paper is part of the ***Journal of Environmental Engineering***, Vol. 120, No. 3, May/June, 1994. ©ASCE, ISSN 0733-9372/94/0003-0527/$2.00 + $.25 per page. Paper No. 3734.

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Cost Analysis for Pollution Prevention

Many pollution prevention opportunities cost very little to implement. But after the inexpensive opportunities have been implemented, facilities must consider those process changes that require research, testing, and capital investment. Process changes can affect a wide range including: environmental compliance, health and safety protection, oversight and management requirements, insurance premiums, and others. Determining the true costs and savings from pollution prevention can be a challenge for facilities.

The pollution prevention cost analysis should compare the total costs of the current process to the total costs of the pollution prevention alternative. To meet Pollution Prevention Planning requirements (Chapter 173-307 WAC), compliance and oversight costs must be included. The objective is to ensure that a pollution prevention opportunity is not rejected prematurely. It's easy to overlook the less obvious, but relevant costs.

Using Net Present Value for Economic Analysis

Net present value (NPV) or discounted cash flow analysis is the most widely recommended method for evaluating financial investments. It is particularly important to use for long-term capital investments with many costs and potential salvage value. To calculate NPV, begin with a cash flow analysis. Then chose a discount rate is chosen that reflects the rate of inflation and the opportunity cost of capital (i.e., what rate of return the money could earn safely elsewhere). The discount rate is applied to each of the future-period cash flows in proportion to how distant they are according to the following formula:

$$\text{Present Value of an Amount} = \frac{\text{Future Amount}}{(1 + i)^p}$$

where i is the discount rate, and p is the period or year number.

With this method, cash flows in the far future are discounted more than cash flows in the near future. The discounted cash flows are summed up to give the net present value of the cash flow over time.

The advantage of NPV is that it can compare any number of cash flows, no matter how complicated they are, in today's dollars. The lower the discount rate selected, the higher the value of future savings will be and the better a pollution prevention opportunity looks.

The following instructions and tables will help determine the Net Present Value of a current process and a pollution prevention alternative. See Table 4 for examples of costs to consider.

Instructions for completing Tables 2 and 3 are as follows:

Row 1: Enter the expected investment for each of the five years. This is an expense, or a negative number.

Row 2: Enter the expected revenue for each of the five years. This is income, or a positive number. If revenues will not be affected by either alternative, leave this row blank.

Row 3: Enter the expected usual costs for each of the five years. These are expenses or negative numbers.

Row 4: Enter the expected compliance costs for each of the five years. Compliance costs are those which are necessary to comply with environmental regulations. If you can be penalized for not spending the money, it's a compliance cost.

Row 5: Enter the expected oversight costs for each of the five years. Oversight costs are all the extra costs you incur because your facility uses hazardous substances or generates waste, including but not limited to regulatory research, permit applications, and inspections.

Row 6: Subtract expenses (line 1,3,4,5) from income (line 2) to determine the annual operating income.

Row 7: Enter the annual depreciation of the process equipment.

Row 8: Subtract depreciation (line 7) from operating income (line 6) to get taxable income.

Row 9: Calculate and enter the amount paid in business taxes on taxable income.

Row 10: Enter the depreciation amount again (line 7). Depreciation is not a real cash expense, but it is used for tax accounting purposes.

Row 11: Add depreciation (line 10) and subtract taxes (line 9) to the total taxable income (line 8) to get the actual annual cash flow from the process.

Row 12: To determine the value of future cash flows today, you need to choose a discount rate. The rate usually reflects the expected inflation rate plus the opportunity cost of capital. (the rate you could get by investing the money elsewhere). Using the Present Value Factor (PVF) table (see Table 1), enter the discount factors for the chosen discount rate. *For example, you may want to discount future cash flows at 10%. Enter the factors in Years 1-5 for the 10% row in the PVF table, into Row 12 of the cash flow table.*

Row 13: Multiply the annual cash flow by the discount factor to determine the present value today of the cash flow in each year.

Row 14: Sum all of the annual discounted cash flows to determine the Net Present Value of the process. This is how much the process is worth to you over the next five years, in today's dollars.

Table 1. Present Value Factors

Discount Rate	YEAR 1	2	3	4	5
5%	0.95	0.91	0.86	0.82	0.78
10%	0.91	0.83	0.75	0.68	0.62
15%	0.87	0.76	0.66	0.57	0.50
20%	0.83	0.69	0.58	0.48	0.40

Table 2. Costs of Current Process (name)

ROW		CASH FLOW YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
1	*subtract* Investment					
2	*add* Revenues					
3	*subtract* Usual Costs					
4	*subtract* Compliance Costs					
5	*subtract* Oversight Costs					
6	*total* Operating Income					
7	*subtract* Depreciation					
8	*total* Taxable Income					
9	*subtract* Taxes					
10	*add back* Depreciation					
11	*total* Cash Flow					
12	*(from table)* Present Value Factor (PVF)					
13	*multiply* Cash Flow x PVF					
14	*sum* Row 13		= NPV			

Table 3. Costs of Pollution Prevention Alternative

ROW		CASH FLOW YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
1	*subtract* Investment					
2	*add* Revenues					
3	*subtract* Usual Costs					
4	*subtract* Compliance Costs					
5	*subtract* Oversight Costs					
6	*total* Operating Income					
7	*subtract* Depreciation					
8	*total* Taxable Income					
9	*subtract* Taxes					
10	*add back* Depreciation					
11	*total* Cash Flow					
12	*(from table)* Present Value Factor (PVF)					
13	*multiply* Cash Flow x PVF					

TABLE 4.

Typical Costs and Activities
to Consider in Pollution Prevention Economic Analysis

USUAL COSTS	COMPLIANCE COSTS	OVERSIGHT COSTS
Depreciable Capital Costs	Receiving Area	Purchasing
engineering	spill response equipment	product/vendor research
procurement	emergency response plan	regulatory impact analysis
equipment		inventory control
materials	Raw Materials Storage	
utility connections	storage facilities	Engineering
site preparation	secondary containment	hazard analysis
facilities	right-to-know training	sampling and testing
installation	reporting and record-keeping	
	safety training	Production
Operating Expenses	safety equipment	employee training
start-up	container labels	emergency planning
training		medical monitoring
initial raw materials	Process Area	re-work
working capital		waste collection
raw materials	safety equipment	disposal management
supplies	right-to-know training	inspections and audits
direct labor	waste collection equipment	
utilities	emission control equipment	Marketing
maintenance	sampling and testing	public relations
salvage value	reporting and record-keeping	
		Management
erating Revenues	Solid & Hazardous Waste	regulatory research
revenues		legal fees
by-product revenues	sampling and testing	information systems
	containers	penalties and fines
	labels and labelling	insurance
	storage areas	
	transportation fees	Finance
	disposal fees	credit costs
		tied-up capital
	Air & Water Emissions control	
	permit preparation	
	permit fees	
	capital costs	
	operating expenses	
	recovered materials	
	inspection and monitoring	
	record-keeping and reporting	
	sampling and testing	
	emergency planning	
	discharge fees	

you have special accomodation needs, please contact Ecology's Hazardous Waste and Toxic Reduction Program at (206) 459-6168 e) or (206) 438-8721 (TDD).

or further assistance in assessing the benefits of waste reduction opportunities please contact one of our regional offices: Northwest 06) 649-7000, Southwest (206) 664-0476, Central (509) 575-2491, Eastern (509) 456-2926.

Use these ideas to cut waste

To reduce waste, schedule projects, projects and more projects. Here are more than 90 that worked for Dow Chemical

K. E. Nelson, Dow Chemical U.S.A., Plaquemine, La.

THE IDEAL WAY to reduce waste is to avoid making it in the first place. When this is not practical, a second technique is often used: recycling waste products back into the process. Both approaches work. Specific improvements involve raw materials, reactors, heat exchangers, pumps, furnaces, distillation columns, piping and control schemes.

Waste reduction pays. All of Dow's Divisions in the U.S. Area have active waste reduction programs. The Louisiana Division's program began in 1981 as an energy conservation program. It was called an "energy contest" and employees were encouraged to submit ideas for projects that would save energy. In 1983, the contest was expanded to include projects that would improve yields and reduce waste.

In 1987, Dow formalized its U.S. Area waste reduction program as "WRAP," an acronym for "Waste Reduction Always Pays." The WRAP program was quickly incorporated into the Louisiana Division's ongoing contest and gave added emphasis to waste reduction efforts.

Contest projects have been well documented since 1981 and nearly all the ideas discussed in this article are based on process changes that have been made at plants in the Louisiana Division. Where appropriate, specific examples are given to help clarify important points. In addition, brief descriptions of six award-winning waste reduction projects from various Dow locations in the U.S. are summarized. They further illustrate how waste reduction concepts and principles have been applied to real-world situations.

While our primary focus will be on projects that reduce waste, many of the modifications discussed will also save energy.

What is waste? Waste includes streams or materials that are:

- Vented to the air
- Discharged to the water
- Sent to landfill
- Sent to an incinerator
- Sent to a flare
- Sent to a biological treatment facility.

The two most common waste reduction techniques are to make less waste initially and to recycle waste products back to the process. Sometimes, it is also possible to reduce emissions by operating waste treatment units more efficiently, but that is not the concern of this article. Also, this article will not discuss the nature of the waste (i.e., hazardous or nonhazardous, toxic or nontoxic, flammable or nonflammable, etc.).

Although this article does not represent an exhaustive study of all possible ways of reducing waste, it does contain a wealth of practical ideas. It can thus serve as the basis for discussion and brainstorming. We'll begin with ideas associated with raw materials.

Six award-winning waste reduction projects

Each year, as part of its WRAP (Waste Reduction Always Pays) program, The Dow Chemical Company recognizes outstanding waste reduction achievements at its various production sites in the United States. The following examples illustrate the variety of projects and the magnitudes of both waste reduction and money saved that is possible.

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Dow's Western Division saved more than $3 million/yr in an agricultural chemicals plant by implementing a system to recycle a viscous tar/catalyst mixture. The new system cost $100,000 and reduced tar formation in the plant by 43 percent. Previously, this waste stream had to be shipped to other Dow sites for incineration.

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Employees at Dow's polystyrene plant in Allyn's Point, Conn., reduced waste by 90,000 lb/yr when they totally eliminated an intermediate processing step. Plant technicians had questioned its value and a series of experiments verified that the intermediate step was unneeded. This process improvement saved $150,000/yr.

• • • • • •

The specialty herbicides plant in Dow's Michigan Division concentrated on ways to reduce, recycle or reuse waste byproducts. Employees made a series of process improvements, including several relatively simple modifications to their operating procedures. Results were outstanding. Production was substantially increased while incinerated wastes were cut by 43 percent. Raw material savings were $3.4 million/yr.

• • • • • •

Dow's Louisiana Division chlorine plant eliminated more than 4.5 MM lb/yr of waste by improving its collection system for a dilute caustic stream. The key idea was to use corrosion-resistant piping to prevent cross-contamination between adjacent conduits. The new installation saves an additional 4.1 MM lb/yr of hydrochloric acid because neutralizing contaminated caustic is no longer necessary. Total project savings are $890,000/yr.

• • • • • •

A Gulf Coast Acid Team was organized by Dow's Chemicals and Metals Dept. They developed creative ways of recycling byproduct HCl to other Dow processes and expanded the HCl business, signing major customer contracts. Their efforts reduced avoidable neutralization to record lows and saved more than $20 million/yr.

• • • • • •

Employees at a chlor-alkali plant in Dow's Texas Division eliminated 59,000 tons/yr of waste by making more than a dozen separate improvements to the plant. Many of the changes involved converting to computer control or upgrading existing control systems or procedures. Combined savings: $753,000/yr.

Raw materials. Raw materials are usually purchased from an outside source or transferred from an on-site plant. Each raw material needs to be studied to determine how it affects the amount of waste produced. The specifications for each raw material entering the plant should be closely examined.

• **Improve quality of feeds.** Although the percentage of undesirable impurities in a feed stream may be low, it can be a major contributor to the total waste produced by a plant. Reducing the level of impurities may involve working with the supplier of a purchased raw material, working with on-site plants that supply feed streams or installing new purification equipment. Sometimes the effects are indirect (e.g., water gradually kills the reactor catalyst causing formation of byproducts, so a drying bed or column is added).

• **Use off-spec material.** Occasionally, a process can use off-spec material (that would otherwise be burned or landfilled) because the particular quality that makes the material off-spec is not important to the process.

• **Improve quality of products.** Impurities in your own products may be creating waste in your customers' plants. Not only may this be costly, it may cause some customers to look elsewhere for higher quality raw materials. Take the initiative in discussing the effects of impurities with your customers.

• **Use inhibitors.** Inhibitors prevent unwanted side reactions or polymer formation. A wide variety of inhibitors are commercially available. If inhibitors are already being used, check with suppliers for improved formulations and new products.

• **Change shipping containers.** If raw materials are being received in containers that cannot be reused and need to be burned or landfilled, change to reusable containers or bulk shipments. Similarly, using alternative containers for shipping plant products should be discussed with customers.

• **Reexamine need for each raw material.** Sometimes the need for a particular raw material (one which ultimately ends up as waste) can be reduced or eliminated by modifying the process or improving control. The need for algae inhibitors in a cross-flow cooling tower, for example, was cut in half by shielding the water distribution decks from sunlight.

Reactors. The reactor is the heart of the process and can be a primary source of waste products. The quality of mixing in a reactor is crucial. Too often, insufficient design time is spent on scaling up this key parameter and a new production facility has disappointing yields when compared to lab or pilot plant data. The first three ideas listed below are concerned with quality of mixing.

• **Improve physical mixing in the reactor.** Modifications to the reactor such as adding or improving baffles, installing a higher rpm motor on the agitator(s), or using a different mixer blade design (or multiple impellers) can improve mixing. Pumped recirculation can be added or increased. Two fluids going through a pump, however, do not necessarily mix well and an in-line static mixer may be needed to ensure good contacting.

• **Distribute feeds better.** Here is an area that deserves more attention than it typically gets. Fig. 1 (left) illustrates the problem. The reactants enter at the top of a fixed catalyst bed. Part of the feed short-circuits down through the center of the reactor so that there is inadequate time for conversion to the desired products. Conversely, the feed closer to the walls remains in the reactor for a too long a time and "over-reacts" to byproducts that eventually become waste.

Although the average residence time in the reactor is correct, inadequate feed distribution causes both poor conversion and poor yield. One solution is to add some sort of distributor that causes the feed to move uniformly through all parts of the reactor as shown in Fig. 1 (right). Some sort of special collector at the bottom of the reactor may also be necessary to prevent the flow from necking down to the outlet.

• **Improve way in which reactants are added.** The idea here is to get closer to ideal reactant concentrations before the feed enters the reactor. This helps avoid secondary reactions which form unwanted byproducts. The way *not* to add reactants is shown in Fig. 2 (top). It is doubtful that the "ideal" concentration exists anywhere in this reactor. A consumable catalyst, especially, should be diluted in one of the

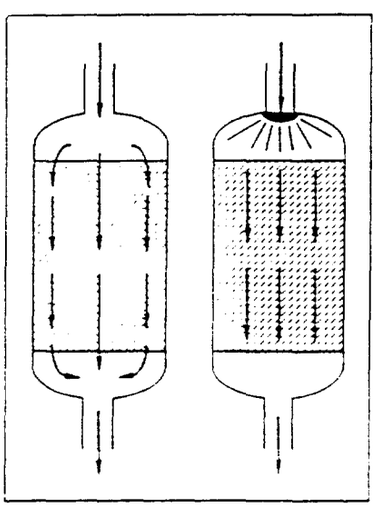

Fig. 1—LEFT: Poor feed distribution in a fixed catalyst bed causes poor conversion and poor yield. RIGHT: Uniform feed flow improves both yield and conversion.

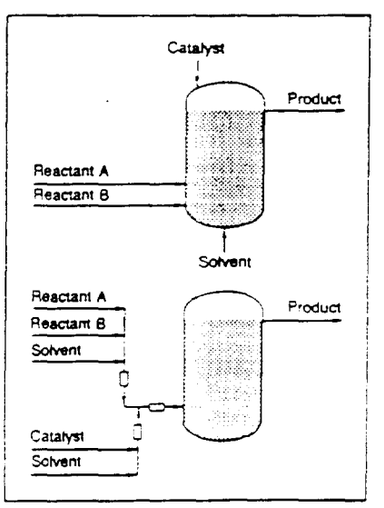

Fig. 2—TOP: Example of poor method for adding feeds to a reactor. BOTTOM: Well-mixed feeds improve reactor performance.

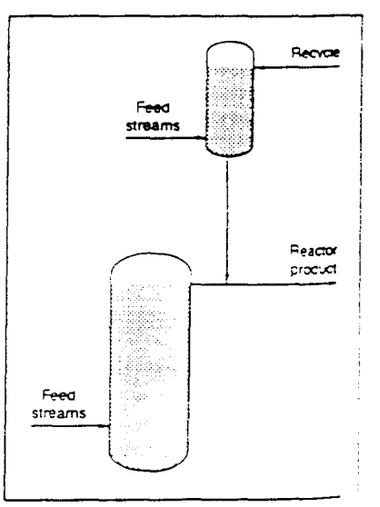

Fig. 3—A separate, small reactor handle cycle waste streams.

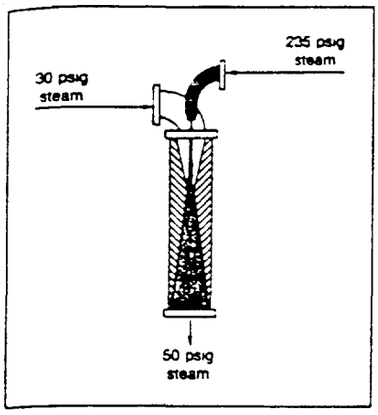

Fig. 4—Thermocompressor upgrades 30-psig steam.

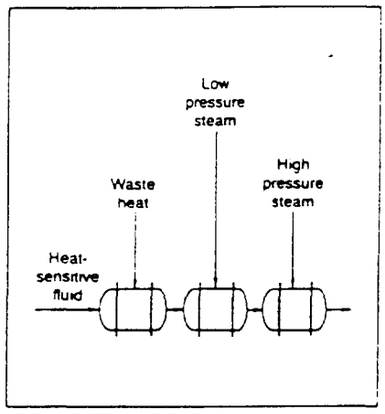

Fig. 5—Staged heating minimizes product degradation.

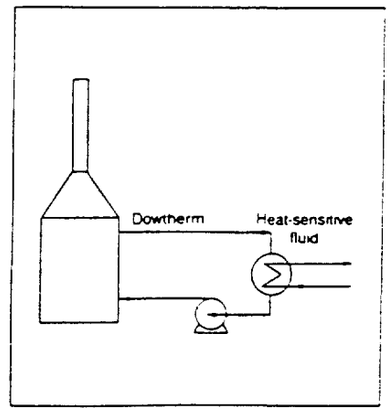

Fig. 6—Use intermediate exchanger to avoid contacting process fluid with hot furnace tube-walls.

feed streams (one which does not react in the presence of the catalyst).

Fig. 2 (bottom) illustrates one approach to improving the situation by using three in-line static mixers.

• **Improve catalyst.** Searching for better catalysts should be an ongoing activity because of the significant effect a catalyst has on reactor conversion and product mix. Changes in the chemical makeup of a catalyst, the method by which it is prepared, or its physical characteristics (size, shape, porosity, etc.) can lead to substantial improvements in catalyst life and effectiveness.

• **Provide separate reactor for recycle streams.** Recycling byproduct and waste streams is an excellent technique for reducing waste, but often the ideal reactor conditions for converting recycle streams back to usable products are considerably different from conditions in the primary reactor. One solution, shown in Fig. 3, is to provide a separate, smaller reactor for handling recycle and waste streams. Temperatures, pressures and concentrations can then be optimized in both reactors to take maximum advantage of reaction kinetics and equilibrium.

• **Examine heating and/or cooling technique.** The technique for heating or cooling the reactor needs to be examined, especially to avoid hot-spots or overheated feed streams, both of which usually give unwanted byproducts.

• **Consider different reactor design.** The classic stirred-tank backmix reactor is not necessarily the best choice. A plug flow reactor offers the advantage that it can be staged, and each stage can be run at different conditions, closely controlling the reaction for optimum product mix (and minimum waste). Many innovative hybrid designs are possible.

• **Improve control.** For a given reactor configuration, there is one set of operating conditions that is "optimum" at any given time. The control system should know those conditions and make them occur, with little fluctuation. Such control may be complex, particularly in the case of batch reactors, but can yield major improvements. In less sophisticated systems, simply stabilizing reactor operation frequently reduces the formation of waste products.

Advanced computer control systems are capable of responding to process upsets and product changes swiftly and smoothly, producing a minimum of unwanted byproducts (see section on process control).

Heat exchangers. Heat exchangers can be a source of waste, especially with products that are temperature sensitive. There are a number of techniques for minimizing the formation of waste products in heat exchangers. Most are associated with reducing tube-wall temperatures.

• **Use lower pressure steam.** When plant steam is available at fixed pressure levels, a quick expedient may be to switch to steam at a lower pressure, reducing tube-wall temperatures.

• **Desuperheat plant steam.** High-pressure plant steam may contain several hundred degrees of superheat. Desuperheating steam when it enters a process (or just upstream of an exchanger) reduces tube-wall temperatures and actually increases the effective surface area of the exchanger because the heat transfer coefficient of condensing steam is ten times greater than that of superheated steam.

• **Install a thermocompressor.** Another method of reducing tube-wall temperature is to install a thermocompressor. These relatively inexpensive units work on an ejector principle, combining high and low pressure steams to produce an intermediate pressure steam. Variable throat models are available that operate like control valves, automatically mixing the correct amounts of high and low pressure steam. The thermocompressor principle is illustrated in Fig. 4 where plant steam at 235 psig is used to upgrade 30-psig steam to 50 psig. Before a thermocompressor was installed, only 235-psig steam was used to supply the required heat.

• **Use staged heating.** If a heat-sensitive fluid must be heated, staged heating can minimize degradation. Begin, for example, with waste heat, then use low pressure steam, and finally desuperheated high pressure steam. A typical arrangement is show in Fig. 5.

• **Use on-line cleaning techniques.** On-line cleaning devices such as recirculated sponge balls or reversing brushes have been on the market for many years. In addition to reducing exchanger maintenance, they also keep tube surfaces clean so that lower temperature heat sources can be used.

• **Use scraped-wall exchangers.** Scraped-wall exchangers consist of a set of rotating blades inside a vertical, cylindrical jacketed column. They can be used to recover saleable products from viscous streams. A typical application

is to recover monomer from polymer tars.

• **Monitor exchanger fouling.** Exchanger fouling does not always occur steadily. Sometimes an exchanger fouls rapidly when plant operating conditions are changed too fast or when a process upset occurs. Other actions such as switching pumps, unloading tankcars, adding new catalysts, or any routine actions can influence fouling.

The first step to reducing or even eliminating these causes of fouling is to identify them by continuously monitoring the fouling factor and correlating any rapid changes with plant events.

• **Use noncorroding tubes.** Corroded tube surfaces foul more quickly than noncorroded tube surfaces. Changing to noncorroding tubes can significantly reduce fouling.

Pumps. Pumps don't usually contribute to waste except in two ways:

• **Recover seal flushes and purges.** Each pump seal flush and purge needs to be examined as a possible source of waste. Most can be recycled to the process with little difficulty.

• **Use sealless pumps.** Leaking pump seals lose product and create environmental problems. Using can-type sealless pumps or magnetically driven sealless pumps eliminates these losses.

Furnaces. Furnace technology is constantly evolving. Furnace manufacturers should be contacted for the latest techniques in optimizing furnace operation and reducing tar formation.

• **Replace coil.** In certain applications, significant improvements can be made by replacing the existing furnace coil with one having improved design features (e.g., tubes with low residence time or designed for split flow). Although it may not be practical to replace an undamaged coil, alternative designs should be investigated whenever replacement becomes necessary.

• **Replace furnace with intermediate exchanger.** Another option is to eliminate direct heating in a furnace (which necessarily exposes the heated fluid to high tube-wall temperatures) by using an intermediate heat transfer medium. This principle is illustrated in Fig. 6.

• **Make use of existing steam superheat.** Even if the temperature required is above the *saturation* temperature of the highest pressure of plant steam available, sufficient *superheat* may be available to totally eliminate the need for a furnace.

In Fig. 7, a process stream is heated to 550°F by using the superheat available in 475-psig steam. No fired heater is used, so the fluid being heated is not subjected to hot tube-wall temperatures.

Distillation columns. Distillation columns typically produce waste in three ways:

1. By allowing impurities to remain in a product. The impurities ultimately become waste. The solution: better separation. In some cases it is desirable to exceed normal product specifications.
2. By forming waste within the column itself, usually because of high reboiler temperatures which cause polymerization. The solution: lower column temperatures.
3. By inadequate condensing, which results in vented or flared product. The solution: improved condensing.

Now let's look at some column and process modifications that reduce waste by attacking one or more of these three problems.

• **Increase reflux ratio.** The most common way of improving separation is simply to increase the reflux ratio. This raises the pressure drop across the column and increases the reboiler temperature (using additional energy), but is probably the simplest solution if column capacity is adequate.

• **Add section to column.** If a column is operating close to flood, a new section can usually be added to increase capacity and improve separation. The new section can have a different diameter and can use trays, regular packing or high-efficiency packing. It does not have to be consistent with the original column.

• **Retray or repack column.** Another method of increasing separation is to retray or repack part or all of a column. Both regular packing and high-efficiency packing typically lower pressure drop through a column, decreasing the reboiler temperature. Packing is no longer limited to small columns; large diameter columns have been successfully packed.

• **Change feed tray.** Don't overlook changing the feed tray. Many columns are built with multiple feed trays, but the valving is seldom changed. In general, the closer the feed conditions are to the top of the column (high lights concentration and low temperature), the higher the feed tray; the closer feed conditions are to the bottom of the column (high heavies concentration and high temperature), the lower the feed tray. Experimentation is easy if the valving exists.

• **Insulate.** Good insulation is necessary to prevent heat losses. Poor insulation requires higher reboiler temperatures and also allows column conditions to fluctuate with weather conditions.

• **Improve feed distribution.** The effectiveness of feed distributors (particularly in packed columns) needs to be analyzed to be sure that distribution anomalies are not lowering overall column efficiency.

• **Preheat column feed.** Preheating the feed should improve column efficiency. Supplying heat in the feed requires lower temperatures than supplying the same heat to the reboiler, and it reduces reboiler load. Often, the feed is preheated by cross-exchange with other process streams.

• **Remove overheads product from tray near top of column.** If the overheads product contains a light impurity, it may be possible to obtain a higher purity product from one of the trays close to the top of the column. A bleed stream from the overheads accumulator can be recycled back to the process to purge the column of lights. Another solution is to install a second column to remove small amounts of lights from the overheads.

• **Increase size of vapor line.** In low pressure or vacuum columns, pressure drop is especially critical; installing a larger vapor line reduces pressure drop and decreases the reboiler temperature.

• **Modify reboiler design.** A conventional thermosiphon reboiler is not always the best choice, especially for heat-sensitive fluids. It may be preferable to use a falling film reboiler, a pumped recirculation reboiler, or high-flux tubes to minimize product degradation.

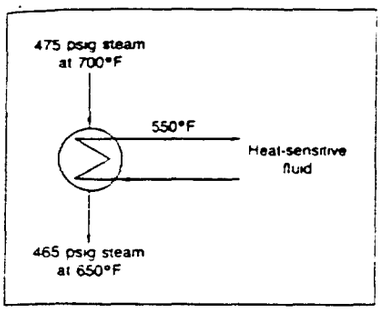

Fig. 7—Use steam superheat to supply high temperature needs.

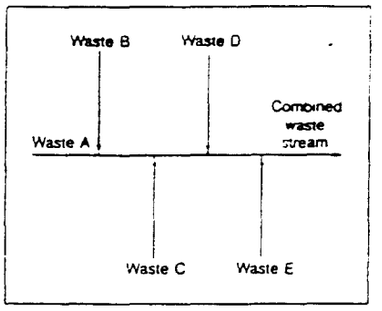

Fig. 8—Examine waste streams individually.

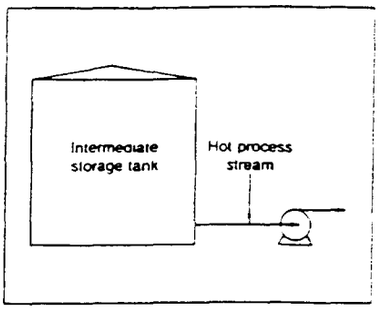

Fig. 9—Pipe hot stream directly into suction line of storage-tank pump.

• **Reduce reboiler temperature.** The same general temperature reduction techniques discussed earlier (in the section on heat exchangers) such as desuperheating steam, using lower pressure steam, installing a thermocompressor, using an intermediate heat transfer fluid, etc., also apply to the reboiler of a distillation column.

• **Lower column pressure.** Reducing the column pressure will also decrease the reboiler temperature and may favorably load the trays or packing as long as the column stays below flood. The overheads temperature, however, will also be reduced, which may create a condensing problem (see following point).

• **Improve overhead condenser.** If overheads are lost because of an undersized condenser, consider retubing, replacing the condenser, or adding a supplementary vent condenser to minimize losses. It may also be possible to reroute the vent back to the process (if process pressure is stable). If a refrigerated condenser is used, be sure to keep the tubes above 32°F if there is any moisture in the stream.

• **Improve column control.** The comments in the Reactor section about closer process control and controlling at the right point apply to distillation columns as well as reactors.

• **Forward vapor overheads to next column.** If the overheads stream is sent to another column for further separation, it may be possible to use a partial condenser and introduce a vapor stream to the downstream column.

Before any equipment modifications are undertaken, it is recommended that a computer simulation be done and that a variety of operating conditions be examined. If the column temperature or pressure changes, equipment ratings should also be reexamined.

Piping. Something as seemingly innocuous as plant piping can sometimes cause waste, and a simple piping change can result in a major reduction of waste. Consider the following piping changes to a process:

• **Recover individual waste streams.** In many plants, various waste streams are combined and sent to a waste treatment facility as shown in Fig. 8. Each waste stream should be considered individually. The nature of the impurities may make it possible to recycle or otherwise reuse a particular stream *before* it is mixed with other waste streams and becomes unrecoverable. Stripping, filtering, drying or some other type of treatment may be necessary before reusing the stream.

• **Avoid overheating lines.** If a process stream contains temperature-sensitive materials, both the amount and temperature level of line and vessel tracing and jacketing needs to be reviewed. If plant steam levels are too hot, a recirculated warm fluid can be used to prevent the process stream from freezing. Choose one that doesn't freeze if the system is shut down in winter. Electric tracing is also an option.

• **Avoid sending hot material to storage.** If a temperature sensitive material is sent to storage it should first be cooled. If this is uneconomical because the stream from storage needs to be heated when it's used, simply piping the hot stream directly into the suction of the storage tank pump as shown in Fig. 9 may solve the problem adequately. Make sure that the storage tank pump can handle hot material without cavitating.

• **Eliminate leaks.** Leaks can be a major contributor to a plant's overall waste, especially if the products cannot be seen or smelled. A good way to document leaks is to measure the quantity of raw materials that must be purchased to replace "lost" streams (e.g., the amount of refrigerant purchased).

• **Change metallurgy.** The type of metal used for vessels or piping may be causing a color problem or be acting as a catalyst for the formation of unwanted byproducts. If this is the case, change to more inert metals (see next point).

• **Use lined pipes or vessels.** Using lined pipes or vessels is often a cheap alternative to using exotic metallurgy. A variety of coatings are available for different applications.

• **Monitor major vents and flare systems.** Flow measurements need not be highly accurate, but should give a reasonable estimate of how much product is lost and when those losses occur. Intermittent losses, such as equipment purges, can be particularly elusive. Corrective action depends on the specific situation; a variety of alternatives exist. Frequently, venting or flaring can be reduced or even eliminated as described in the following paragraph.

• **Recover vented product.** It is often worthwhile to install whatever piping is necessary to recover products that are vented or flared and reuse them in the process (or in another process). Storage tanks, tankcars and tanktrucks are common sources of vented product. A condenser or small vent compressor may be all that is needed for recovery. Additional purification may be necessary before the recovered streams can be reused.

Process control. Modern technology allows us to install highly sophisticated computer control systems that respond

far more quickly and accurately than human beings. We can use that capability to reduce waste. Some suggestions are summarized below.

• **Improve on-line control.** Good process control reduces waste by minimizing cycling and improving a plant's ability to handle normal changes in flows, temperatures, pressures and compositions. Statistical quality control techniques help plants analyze process variations and document improvements. Sometimes additional instrumentation or on-line stream monitors (e.g., gas chromatographs) are necessary, but good control optimizes process conditions and reduces plant trips—a major source of waste.

• **Optimize daily operation.** If a computer is incorporated into the control scheme, it can be programmed to analyze the process continuously and optimize operating conditions. If the computer is not an integral part of the control scheme, off-line analyses can be performed and used as a guide for setting process conditions.

• **Automate startups, shutdowns and product changeovers.** Huge quantities of waste can be produced during plant startups, shutdowns and product changeovers, even when such events are well planned. Programming a computer to control these situations brings the plant to stable operating conditions quickly and minimizes the time spent generating off-spec product. Further, since minimum time is spent in undesirable running modes, equipment fouling and damage are reduced.

• **Program plant to handle unexpected upsets and trips.** Even with the best control systems, upsets and trips occur. Not all can be anticipated, but operators who have lived with the plant for years probably remember most of the important ones and know the best ways to respond. With computer control, optimum responses can be preprogrammed. Then, when upsets and trips occur, the computer takes over, minimizing downtime, spills, equipment damage, product loss and waste generation.

Miscellaneous. In addition to the ideas already discussed, there are a number of other miscellaneous improvements that can be made to reduce waste:

• **Avoid unexpected trips and shutdowns.** A good preventative maintenance program and adequate sparing of equipment are two keys to minimizing trips and unplanned shutdowns. Another key is to provide an adequate warning system for critical equipment (e.g., vibration monitors). Plant operators can be extremely helpful by reporting unusual conditions so that minor maintenance problems get corrected before they become major and cause a plant trip.

• **Use waste streams from other plants.** Within a chemical complex, each plant's waste streams should be clearly identified. The quantity and quality of these streams should be documented, including the presence of trace quantities of metals, halides or other impurities that render a stream useless as a raw material. This list should be reviewed by all plants in the complex to determine if any are suitable as feedstocks.

• **Reduce number and quantity of samples.** Taking frequent and large samples can generate a surprising amount of waste. Many plants find that the quantity and frequency of sampling can be reduced and that the samples can be returned to the process after analysis.

The author

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• **Recover product from tankcars and tanktrucks.** Product drained from a tankcar or tanktruck (especially those dedicated to a single service) can often be recovered and reused.

• **Reclaim waste material.** Sometimes waste products—not all of which are chemical streams—can be reclaimed. Rather than sending them to a burner or to landfill, plants have found ways to reuse them. This may involve physical cleaning, special treating, filtering or other reclamation techniques.

• **Install reusable insulation.** When conventional insulation is removed from equipment it is typically scrapped and sent to landfill. A number of companies manufacture reusable insulation. Their products are particularly effective on equipment where the insulation is removed regularly in order to perform maintenance (e.g., heat exchanger heads, manways, valves, transmitters, etc.).

• **Maintain external painted surfaces.** Even in plants handling highly corrosive materials, *external* corrosion can be a major cause of pipe deterioration. Piping and vessels should be painted before being insulated, and all painted surfaces should be well-maintained.

• **Use more computer communications, less paper.** Computers aren't the tools for every communications chore, but many routine messages can be sent via computer.

• **Find a market for waste products.** Converting a waste product to a saleable product may require additional processing and some creative salesmanship, but it can be an effective means of reducing waste. The converted product should not create a waste problem for the customer.

Take action. Reducing waste is a never-ending activity. Each year, we are faced with new demands, new regulations, new legislation, new challenges and of course, new problems. Amidst all this activity, we never want to lose sight of one extremely important concept: **The way you reduce waste is by installing projects that reduce waste.**

Get results. Waste reduction is not synonymous with lower profits. Nearly every idea listed in this article had a return on investment greater than 30%. Most paid for themselves in less than a year. Finding and installing these kinds of projects helps support other waste reduction projects that have little or no payback.

ACKNOWLEDGMENT

Thanks to all those whose ideas have been included in this article. Dow is fortunate to have a large number of creative, resourceful people who have cultivated the art of looking at even the most adverse situations as opportunities for improvement. Their accomplishments have made this article possible.

A "Mark I" Measurement Methodology for Pollution Prevention Progress Occurring as a Result of Product Design Decisions

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A methodology for assessing progress in pollution prevention resulting from product redesign, reformulation or replacement is described. The method compares the pollution generated by the original product with that from the modified or replacement product, taking into account, if desired, the various lifecycle stages of the product. The pollution prevented (or sometimes increased) as a consequence of the redesign is delineated with respect to the media affected (water, air, or soil/groundwater) and with respect to three "categories" of pollution impact (human health impacts, use impairment impacts and disposal capacity impacts). The method also provides information as to the specific "classes" of pollution prevented such as toxic organics, heavy metals, global warmers, nutrients, aquatic life toxicants or hazardous wastes. The methodology is extendable to pollution prevention projects of all types, not just product redesign.

INTRODUCTION

Within EPA's hierarchy of preferred environmental protection options, source reduction and recycling stand as the top two preferred techniques. Source reduction simply means "cutting back on the amounts of wastes created" while recycling simply means "using, for beneficial purposes, materials which would otherwise have been destroyed, sent to waste treatment or discharged into the environment as wastes." Pollution prevention is, for practical purposes, equated to source reduction in the wording of the Pollution Prevention Act of 1990 and the EPA has mounted a considerable effort within the last several years to promote the adoption of pollution prevention concepts on a broad scale across the United States.

The contributions that pollution prevention can make to improvements in environmental quality during the 1990s are thought to be very substantial. At least in general terms, pollution prevention has now been adopted as a common goal by regulatory agencies at federal, state and local levels, by industry, by various public interest groups and by the public at large.

To determine its contributions on a quantitative basis, progress in pollution prevention will have to be measured. Such measurements will tell us how far we have come and, possibly, how much farther there is to go in utilizing this old, but newly-emphasized tool for improving environmental quality.

Macro-scale and Micro-scale Methodologies

Two types of measurement tools are required—one for the "macro-scale" and another for the "micro-scale." The macro-scale tool is applicable on an area-wide, industry-wide or facility-wide basis. It involves the use of survey instruments and techniques to determine the reductions in pollution generation occurring over specified periods of time. EPA's annual Toxics Reduction Inventory (TRI) is an example. The micro-scale tool, on the other hand, would assess the changes in the generation of pollutants occurring as the result of applying a specific pollution prevention technique to a specific waste-generating process or product.

Recent literature on pollution prevention progress measurement [*1, 2, 3, 4, 5, 6*] and a 1993 workshop on this subject [*7*] focus primarily on macroscale methods. Two articles [*8, 9*] discuss pollution prevention progress in terms of the types of environmental impacts prevented, a concept applicable to micro-scale methodology. Other articles which can be related to the micro-scale concept [*10, 11*] discuss chemical substitution

in the reformulation of products and the use of less toxic alternatives in manufacturing—both actions being forms of pollution prevention.

A major step with regard to macro-scale methodology was a provision in the recent Pollution Prevention Act which required the addition to the TRI of a "toxic chemical source reduction and recycling report." This addition, first used in 1992, will begin to quantify the pollution prevention progress occurring nation-wide with respect to certain toxic chemicals discharged by U.S. industry. Progress will be assessed through the tabulation of such information as the quantities of the chemicals entering wastes or otherwise released to the environment, the amounts recycled at the facility or elsewhere, etc. Furthermore, the act requires that source reduction practices reported be categorized into at least four groups, one of which is "reformulation or redesign or products."

Because of the context in which the questions are being asked and because of the inherent oversimplification needed in a nationwide survey of this type, the progress reported from "reformulation or redesign of products" will necessarily be under-reported! First, it will obtain data only on the "SARA 313 chemicals" and not on other chemicals, RCRA hazardous wastes or nonhazardous solid wastes. Second, it will collect information only on pollution prevented at the manufacturing site. Yet, through astute product design decisions, much pollution can and will be prevented during other stages of a product's lifecycle than the "manufacturing/processing/formulating" stage; most importantly, perhaps, it will occur during product use and at the time the product's useful life ends and the product, itself, becomes a waste.

The methodology described below is a micro-scale tool for measuring pollution prevention progress occurring during any and all stages of a product's lifecycle *but which is attributable to decisions made or actions taken during the product's design stage*. It not only provides a structured presentation of the pollution prevented but it also recognizes and quantifies product designers' contributions to pollution prevention, enables non-manufacturing stage pollution prevention to be considered and should encourage industry to give more thought to minimizing the environmental impacts of a product during every one of its lifecycle stages.

Product Life Cycles

From "womb to tomb," a product may be thought of as going through the following lifecycle stages:

1) Raw materials acquisition and handling
2) Materials manufacture
3) Manufacturing, processing and/or formulating
4) Packaging and distribution
5) Use
6) Maintenance/repair
7) Recycle
8) Disposal

For most products, environmental impacts can and do occur during any one or all of these stages. For example, the mining of ores and the growing of crops produce wastes. Production of petrochemical intermediates or lumbering, shaping and treating of wood all create wastes. Product manufacturing obviously is a source of wastes. Leaks and spillage during packaging and transportation of products occur and, even if not, energy is expended—with consequent environmental effects—during this phase of a product's life. Many products, e.g., insect sprays, brake shoes or backyard grills, inherently produce wastes during their use and some do during their repair, e.g., air conditioners, or their maintenance, e.g., repainting. Wastes can be generated during the separation and processing of materials for recycle and, finally, almost every product, itself, becomes a pollutant or potential pollutant when its useful life has ended, even if it's just "going to a landfill."

A designer is able to influence the raw materials used, the production process employed, the way in which the product is utilized, its life, its "repairability," its recyclability and even the mode of its eventual disposal. Product design decisions which beneficially influence any of the above potential environmental impacts should be encouraged and acknowledged. Such decisions will play a crucial role in our movement towards truly sustainable technologies and being able to measure the pollution prevented as a result of these decisions will become increasingly important.

THE MEASUREMENT CONCEPT

Measuring "pollution prevention" is a little like measuring "the little man who wasn't there." That is, the challenge is to quantify the amount of pollution that will not exist in the future because certain actions or decisions are taken now. For example, if an existing product contains a volatile toxic component which is emitted to the air during product use and, if the product composition is changed to replace the toxic component with a non-toxic one, all else being equal, pollution prevention has been accomplished. One measure of it is the amount of the toxic component that was not emitted. A good analogy might be from the safety field where the measure of success of a safety program is the number of accidents that did not happen as a result of the program.

While a "survey approach" such as the TRI has much merit, it is a macro-scale tool. It provides information at the facility level. The tool needed by individuals responsible for planning and implementing pollution prevention projects, on the other hand, is a micro-scale method, i.e., a "project-by-project" method. With such a tool, the pollution prevented as a result of a specific pollution prevention action, e.g., the redesign of a product, could be known. This methodology uses such a project-by-project approach. It "takes a snapshot" of the pollutants generated by an "original" product and another "snapshot" of those from a "modified" or "redesigned" product. The difference between the "snapshots" reflects the pollution prevented by the redesign. If this "before and after" concept were applied broadly to all pollution prevention projects at a facility, a summation of all of the project-related pollution prevented would, theoretically, provide the kind of data needed for responding, perhaps more accurately than at present, to a pollution prevention survey questionnaire for the facility as a whole.

Assumptions

To begin, some simplifying assumptions are necessary. When comparing products "before redesign" and "after redesign," it must be assumed that the modified product is an exact functional replacement for the original product. That is, the redesigned product performs exactly the same function as the original product that it is to replace. It must also be assumed that the performance of the redesigned product is, for practical purposes, the same as that of the original product. Next, the "unit-of-use" for both products must also be identical. That is, if the product is paint, both products will cover the same amount of surface. Note that this is not necessarily the same volume of paint. If the product is a container, both containers will hold the same amount of material. Finally, product life must be taken into account. If the useful life of the redesigned product is 150 percent of that of the original product, then the pollutants from the original product must be compared with two-thirds, i.e., 100/150, of the pollutants from the redesigned product.

Next, the "kind" of pollution prevented needs to be defined. Any one can understand that preventing a pound of wastepaper from going to a landfill has a different environmental benefit than preventing a pound of PCBs from contaminating the air of an office building. This implies immediately that, unless we put these impacts on some standard scale, there must be a set

of "categories of environmental impacts" within each of which the amount of pollution prevented can be assessed separately. This is so in order that we do not measure and then sum together pollutional "apples and oranges."

Pollution "Categories"

The two traditional categories of pollution impacts are "human health impacts" and "use impairment/ecological impacts." These impacts can, of course, be experienced in each of the three media, viz., air, water and soil/groundwater. Therefore, broad categories, within which amounts of pollution prevented might be usefully compared, could be:

In air:

Category A1—Human Health Impacts (e.g., cancer, brain damage, asbestosis, etc.)
Category A2—Use Impairment Impacts (e.g., smog, acid rain, ozone depletion, odors, etc.)

In water:

Category W1—Human Health Impacts
Category W2—Use Impairment Impacts (e.g., fish kills, eutrophication, etc.)

In soil/groundwater:

Category S1—Human Health Impacts
Category S2—Use Impairment Impacts (e.g., soil poisoning, excess salinity, etc.)

In addition to the above six categories, there is one more of special significance for soil/groundwater. It is "disposal capacity impacts"—the fact that the very quantity of wastes which will or may have to be disposed of into landfills effectively reduces their capacity for accepting future wastes. Hence, a third Category for the soil/groundwater medium is proposed:

Category S3—Disposal Capacity Impacts

There is also increasing concern regarding indoor air quality and, therefore, for products resulting in releases to indoor air, an indication of the amount of indoor air pollution prevented would also be useful. This can be dealt with by considering "indoor air" simply as a sub-division of the air medium. Also, note that only human health impacts and certain use impairment impacts, e.g., odors, affect indoor air quality. That is, impacts such as smog, ozone depletion and global warming do not occur in indoor air but only result when the causative pollutants are released into the outdoor environment. A credible measurement method should take this into account.

The pollutants generated by a product can, of course, cause impacts in one or a number of the above categories as a result of releases during any of the stages of a product's lifecycle. It would be helpful, therefore, for the methodology to be able to relate pollution prevented to the particular stage or stages of a product's lifecycle in which the user may be interested as well as to be able to reflect the pollution prevented when taking all lifecycle stages into account.

Pollutant "Classes"

Having information at the category level as described above will be helpful, but better judgments can be made as to progress achieved if questions could be answered such as, "How much pollution that causes global warming, human cancer, aquatic toxicity, acid rain or use of landfill capacity *did not occur* as a result of the pollution prevention action taken?" This points to a need for a further breakdown of the kinds of pollution prevented—a breakdown into specific pollutant classes. While the number of such classes is potentially quite large, from a practical standpoint there are only a relative few that are of greatest concern. The following seven encompass the major health-related pollutants:

1) Carcino-, Terato- and Mutagens
2) Fine Fibers
3) Heavy Metals
4) Pathogens
5) Radioactives
6) Toxic Inorganics
7) Toxic Organics

As for use impairment impacts, the following 13 classes of pollutants seem reasonable, at least for a start:

1) Acid Rain Precursors
2) Aquatic Life Toxicants
3) Biological Oxygen Demanders
4) Chemical Oxygen Demanders
5) Corrosives
6) Dissolved Solids
7) Global Warmers
8) Nutrients
9) Odorants
10) Ozone Depleters
11) Particulates
12) Smog Formers (VOCs + NO_x)
13) Suspended Solids

Two pollutant classes seem appropriate within the Disposal Capacity Impacts Category because of the different types of facilities and materials handling capabilities required for each:

1) Solid Wastes 2) Hazardous Wastes

All solid or liquid substances can be considered as potential "solid wastes" since, upon disposal to a landfill, they would take up some of its holding capacity. While users of the methodology may, of course, use various definitions of "hazardous wastes," in general, all materials which are recognized as toxic, corrosive, explosive, etc. can be considered to fall within this Class.

With this breakdown into 22 classes, a reasonable "handle" on appreciating and quantifying the various kinds of pollution affected by a particular pollution prevention project would seem possible. Individual users of the method may, however, add classes to or remove classes from the suggested list of 22 as they desire.

Chemical-by-chemical Measurement

It is recognized that there are many virtues in measuring pollution prevention progress on a chemical-by-chemical basis rather than by the kind of environmental impacts prevented. In fact, chemical-by-chemical prevention data is what is being obtained from the amended TRI. Hence, it will be useful for a pollution prevention progress measurement method to employ both the chemical-by-chemical approach and use of the above categories and pollutant classes. This method allows both approaches. The advantage of using the impact-by-impact approach, is that pollutional "apples and oranges" can be logically segregated and then summed.

Pollutant "Potencies"

It is clear that not all toxic substances, not all carcinogens, not all ozone depleters and not all nutrients have the same "potency." Not only that, but the physical and/or chemical forms of such materials will also affect the degree and type of their environmental and/or health impacts as will the local levels of exposure involved. In the long run, therefore, one will want to add additional levels of sophistication to this measurement methodology. For example, one might use "weighting factors" for the various pollutants in each Class, in order to relate "amount of pollution prevented" more directly to "amount of environmental risk prevented" and even to take local conditions into account. However, this degree of sophistication is not being considered here in this "Mark I" methodology. It is an obvious "next step," but this more basic first step, i.e., a method for simply classifying, quantifying and displaying amounts of pollution prevented, is needed first.

Table 1 An Illustrative Example of Product Redesign for Pollution Prevention Purposes

Assumptions[a]

Product:	rubber cement
Unit-of-Use:	1 gallon
Original Product Life:	1 application
Modified Product Life:	1 application

Product Constituents	ORIGINAL Product	MODIFIED Product
adhesive	4.3 lb	4.4 lb
toluene	3.5	0.61
water	0.42	0.22
heptane		3.12
	8.22 lb	8.35 lb

1) For the Original Product composition:
   a) During manufacture, 0.14 lb toluene escapes to the air.
   b) During manufacture, 0.15 lb phosphates and 0.83 lb water is used for equipment cleaning and is discharged as wastewater.
   c) During manufacture, 0.11 kwh electric energy from a coal-fired power plant is consumed.
   d) During use, 3.2 lb toluene evaporates; 0.30 lb reacts with the adhesive.
   e) During use, 1.0 lb adhesive evaporates.
2) For the Modified Product composition:
   a) During manufacture, only a trace of toluene, 0.0059 lb (5.9 millipounds), escapes to the air but 0.36 lb heptane does.
   b) During manufacture, 0.094 lb phosphates and 0.69 lb water is used for equipment cleaning and is discharged as wastewater.
   c) During manufacture, 0.14 kwh (coal-fired source) is consumed.
   d) During use, 3.0 lb heptane evaporates; 0.12 lb is adsorbed onto the "set" adhesive but will desorb over time after being landfilled, i.e., during the disposal lifecycle stage.
   e) During use, 0.52 lb toluene evaporates; 0.09 lb reacts with the adhesive.
   f) During use, 1.33 lb adhesive evaporates.
3) For both compositions:
   a) During use, half of the water reacts with the adhesive when the adhesive "sets"; 10 percent remains unreacted but is "permanently" occluded within the "set" adhesive; the remainder evaporates.
   b) During use, nine-tenths of the unevaporated adhesive "sets"; the other tenth remains unreacted and is absorbed into the "set" adhesive; this unreacted adhesive can leach out after landfilling, i.e., during disposal.
   c) During disposal, the "set" adhesive goes to a landfill.
4) Toluene is a "toxic organic," a "smog former," an "odorant," a "biological oxygen demander," a "chemical oxygen demander," and a "hazardous waste."
5) The adhesive is a "toxic organic," an "odorant," an "aquatic life toxicant," and a "hazardous waste."
6) The "set" adhesive (adhesive + toluene + water) has no human wealth or use impairment impacts but is a "solid waste."
7) Heptane is a "global warmer," a "smog former" and a "solid waste."
8) Phosphates are a "nutrient," a "dissolved solid" and a "solid waste."
9) The product is used indoors.

NOTE: This example considers only three lifecycle stages, viz., Manufacturing, Use, and Disposal
a. Even though Environmental Progress normally uses S.I. Units, it is felt that many potential users of this methodology would find the method easier to understand and apply if English Units are used.

Pollution Prevention Can Increase Pollution

Finally, while product redesign to prevent pollution is a worthy goal, it should be recognized that, in most cases, a product design change will decrease one set of pollutional impacts *while simultaneously increasing others*. A good measurement methodology should highlight this "fact of life." The concurrent pollution increases will often be quite acceptable, but analysis and reasoned judgment is required as to whether the impacts increased are less significant or, possibly, more significant than the impacts reduced. Any increase in pollution, i.e., negative pollution prevention, resulting from a product design change should be clearly recognized and clearly delineated when the overall "pollution prevention" (the net pollution prevention) from a product redesign is measured and reported.

A PROGRESS MEASUREMENT EXAMPLE

Perhaps the best way to present this methodology is to apply it to an example—a *fictional* example created to elucidate the proposed method and some of its special features. The example case chosen, a reformulation of rubber cement, is summarized in Table 1. The formulations presented and the assumptions made are for illustrative purposes and are not necessarily factual. This includes the classes ascribed to the various pollutants.

Superficial consideration of a proposal to reformulate rubber cement by using heptane as the solvent instead of toluene would lead most individuals to a ready conclusion that, from a pollution prevention standpoint, this would be a "win-win" situation since a known health hazard, toluene, would be replaced by an "innocuous" solvent, heptane. A more detailed examination of the proposal, using this methodology, would still lead most decision-makers to the same conclusion, but, the method would highlight for them that the proposal is, in fact, a "win some" while also "losing some" matter.

Unit-of-Use and Product Life

In this example, all figures are given in "pounds per unit-of-use," in this case, "pounds per gallon of rubber cement." As described above, an appropriate "unit-of-use" needs to be chosen for each product. For rubber cement, a volume measure such as "one gallon" or "one 55-gallon drum" is appropriate if the performance of the original and modified products are

exactly the same, i.e., if the same volume of cement is required to adhere the same amount of surface area. On the other hand, if the modified cement is a more effective product and the modified formulation requires 10 percent less cement for the same surface area, an appropriate unit-of-use might be "the amount needed to adhere 100 sq ft of surface." Note also that the "product life" is considered to be the same, viz., "one application."

Example Results

Table 2 presents an array of some of the data which the proposed methodology can provide to help decision-makers discern and weigh the "wins" vs. the "losses." The pollution prevented and the pollution increased by the reformulation as delineated in the following two paragraphs are all to be found in the first column of numbers under Part 1 of Table 2. Note that results are presented to only two significant figures—higher precision is not felt to be justified for this or similar methods.

In terms of total pollutant load on the overall environment, the reformulated product would lead to 0.46 lb *more* pollution than the original product—remember, this means 0.46 lb per 1 gal of rubber cement. One and one-tenth pound more pollution would enter the air but 0.55 lb less waste would go into the soil/groundwater and 0.056 pounds, 56 "millipounds," less pollutants would enter surface waters. Interestingly, while net air pollution is being increased, indoor air pollution will actually be decreased by some 2.4 lb. This seeming anomaly results from the fact that certain pollutants have impact on outdoor air pollution but not on indoor air quality. Toluene, for example, pollutes indoor air because of its health impacts and its odor, but heptane, even though released indoors, has no impact on indoor air quality since it is assumed, for this example, to be non-toxic and odorless. Its global warming and smog forming properties do not contribute to indoor air pollution.

As far as health impacts are concerned, the redesigned product would lead to the prevention of 2.5 lb of health impacting pollution, the great bulk of it in the air medium but including a 0.023 lb reduction in soil/groundwater. Indoor air pollution would be reduced by only 2.4 lb since the air emissions occurring during both the manufacturing and disposal stages do not enter an indoor air environment. Use impairment impacts would increase by a net 0.99 lb. This consists of a 1.1 lb increase in net pollution going to air combined with 0.056 lb of pollution prevented in water and 0.023 lb prevented in soil/groundwater. The effect on disposal capacity is to reduce the amount of material potentially to be disposed of within a landfill by 0.55 lb.

From the above, it is obvious that some pollution would be prevented by the reformulation but that other kinds of pollution would be increased. In fact, one now becomes a little less certain of the net environmental benefit of the redesign.

Highlights of the rest of the measurement results presented in Table 2, Part 1 include the following:

Three and one-half pounds more heptane will be released to the environment if the redesigned product is adopted. This heptane will impair use of the air environment in some way but will not have any human health impact. On the other hand, 2.8 pounds less toluene will enter the environment. This 2.8 lb of toluene prevented would have had a health impact and the same 2.8 lb would simultaneously have impaired air use in other ways. Toluene pollution of indoor air would have been decreased by 2.7 lb.

Thirty-one hundredths of a pound more adhesive would enter the environment, the net result of 0.33 lb more to the air but 0.023 lb less to the soil/groundwater. The amount of "set" adhesive to be disposed of would be decreased by 0.52 lb; phosphates in wastewater would be reduced by 0.056 lb; and a small amount of water, 0.020 lb, which would otherwise have become part of the solid waste, would be eliminated.

Effect of Energy Consumption

Note that a variety of pollutants (CO_2, solid waste, SO_x, NO_x, CO, particulates, and H_2SO_4) are listed in Table 2 but were not part of the product nor, in fact, even mentioned in the Assumptions. These are energy-related pollutants and are included as an indication of the pollution prevented (or, as in this case, increased) because of changes in the amount of energy consumed in producing the modified product vs. the original product. If the changes in energy consumption are known along with the sources of the energy used, i.e., is the electric energy from a coal-fired generating plant, for example, or is the thermal energy from an oil-fired boiler, etc., data are available [*12*] reflecting the "national average" pollution releases per kwh or per million Btu for energy derived from particular types of sources—see Table 3. This methodology takes this into account.

Pollutant Classes Prevented

Referring again to Table 2, the data in the first column of Part 2 show the amounts of pollution prevented for the rubber cement example on a pollutant class-by-pollutant class basis. It can be seen that in the Human Health Impact category, the redesigned product prevents a net 2.5 lb of toxic organics. Moreover, the table reveals that the specific pollutants involved are toluene and adhesive—a 2.8 lb decrease in toluene partially offset by a 0.31 lb increase in adhesive. The table also shows that there is a slight increase, 980 μlb (micropound) in Toxic Inorganic releases resulting from the increased energy usage.

Similarly, in the Use Impairment Impact category, the table reveals that the reformulation of the rubber cement causes increases in the following pollutant Classes: global warmers, 3.6 lb; smog formers, 0.67 lb; corrosives, 1.0 mlb; acid rain precursors, 980 μlb; particulates, 130 μlb; and aquatic life toxicants, 60 μlb. On the plus side, the reformulation will prevent the following pollution: odorants, 2.5 lb; dissolved solids, 56 mlb; and nutrients, 56 mlb (it needs to be emphasized that these numbers are *not* additive—for example, the same phosphate that is a dissolved solid is also a nutrient).

The pollutant class data indicate that the most significant negative impacts of the product redesign are from the 3.6 lb of global warmers and the 0.67 lb of smog formers which will be added to the environment. The global warmers are heptane, CO_2 and NO_x, each of which is increased. The increase in smog formers is the net result of the increase in heptane and the decrease in toluene along with minor increases in NO_x and CO.

One can also derive from the table that the difference between the odorants prevented (2.5 lb) and the smog formers prevented (− 0.67 lb) results primarily from the 3.5 lb increase in heptane release which affects smog formation but not odor.

With regard to Disposal Capacity Impacts, the 0.53 lb decrease in solid wastes is seen to be largely due to the decrease in the amount of "set" adhesive formed when using the reformulated product. Of note, but not of major significance, is the increase of 9.2 mlb in the amount of solid waste arising from the increased power requirement for the modified product. The 23 mlb decrease in hazardous wastes reflects the need to dispose of slightly less unreacted adhesive when the modified product is used.

Pollutant Amounts Are Compared—Not Risks

Being made aware of these kinds of implications in waste generation should help in arriving at a better sense of the net benefit or net detriment to the environment that will occur if

Table 2

Part 1—Pollution Prevention Progress Achieved per Gallon of Rubber Cement for the Manufacturing, Use, and Disposal Lifecycle Stages by Pollution Category, by Pollutant and by Medium

		Pollutants												
Impacts on:	Total	heptane	toluene	adhesive	"set" adhesive	CO_2	phos-phates	water	solid wastes	SO_x	NO_x	partic-ulates	CO	H_2SO_4
Overall Environment	−0.46 lb	−3.5 lb	2.8 lb	−0.31 lb	0.52 lb	−71 mlb	56 mlb	20 mlb	−9.2 mlb	−670 μlb	−310 μlb	−130 μlb	−110 μlb	−60 μlb
Water	56 mlb						56 mlb							−60 μlb
Soil/Groundwater	0.55 lb			23 mlb	0.52 lb			20 mlb	−9.2 mlb					
Air	−1.1 lb	−3.5 lb	2.8 lb	−0.33 lb		−71 mlb				−670 μlb	−310 μlb	−130 μlb	−110 μlb	
(Indoor Air)	(2.4 lb)		(2.7 lb)	(−.33 lb)										
Human Health	2.5 lb	—	2.8 lb	−0.31 lb	—	—	—	—	—	−670 μlb	−310 μlb	—	−110 μlb	—
Water														
Soil/Groundwater	23 mlb			23 mlb										
Air	2.5 lb		2.8 lb	−0.33 lb						−670 μlb	−310 μlb		−110 μlb	
(Indoor Air)	(2.4 lb)		(2.7 lb)	(−0.33 lb)										
Use Impairment	−0.99 lb	−3.5 lb	2.8 lb	−0.31 lb	—	−71 mlb	56 mlb	—	—	−670 μlb	−310 μlb	−130 μlb	−110 μlb	−60 μlb
Water	56 mlb						56 mlb							−60 μlb
Soil/Groundwater	23 mlb			23 mlb										
Air	−1.1 lb	−3.5 lb	2.8 lb	−0.33 lb		−71 mlb				−670 μlb	−310 μlb	−130 μlb	−110 μlb	
(Indoor Air)	(2.4 lb)		(2.7 lb)	(−.33 lb)										
Disposal Capacity	0.55 lb	—	—	23 mlb	0.52 lb	—	—	20 mlb	−9.2 mlb	—	—	—	—	—
Soil/Groundwater	0.55 lb			23 mlb	0.52 lb			20 mlb	−9.2 mlb					

Part 2—Pollution Prevention Progress Achieved per Gallon of Rubber Cement for the Manufacturing, Use, and Disposal Lifecycle Stages by Pollution Category, Pollutant Class, and Pollutant for the Overall Environment

		Pollutants												
Pollutant Classes:	Total	heptane	toluene	adhesive	"set" adhesive	CO_2	phos-phates	water	solid wastes	SO_x	NO_x	partic-ulates	CO	H_2SO_4
Human Health Impacts														
Toxic Inorganics	−980 μlb									−670 μlb	−310 μlb			
Toxic Organics	2.5 lb		2.8 lb	−0.31 lb									−110 μlb	
Use Impairment Impacts														
Acid Rain Precursors	−980 μlb									−670 μlb	−310 μlb			
Aquatic Life Toxicants	−60 μlb													−60 μlb
Corrosives	−1.0 mlb									−670 μlb	−310 μlb			−60 μlb
Dissolved Solids	56 mlb						56 mlb							−60 μlb
Global Warmers	−3.6 lb	−3.5 lb				−71 mlb					−310 μlb			
Nutrients	56 mlb						56 mlb							
Odorants	2.5 lb		2.8 lb	−0.31 lb										
Particulates	−130 μlb											−130 μlb		
Smog Formers	−0.67 lb	−3.5 lb	2.8 lb								−310 μlb		−110 μlb	
Disposal Capacity Impacts														
Hazardous Wastes	23 mlb			23 mlb										
Solid Wastes	0.53 lb				0.52 lb			20 mlb	−9.2 mlb					

NOTE: Negative numbers signify pollution INCREASES. "mlb" denotes millipounds (1/1,000 lb) and "μlb" denotes micropounds (1/1,000,000 lb). Also, the numbers in Table 2 may sometimes appear not to add correctly since the numbers displayed have been rounded to only two significant figures.

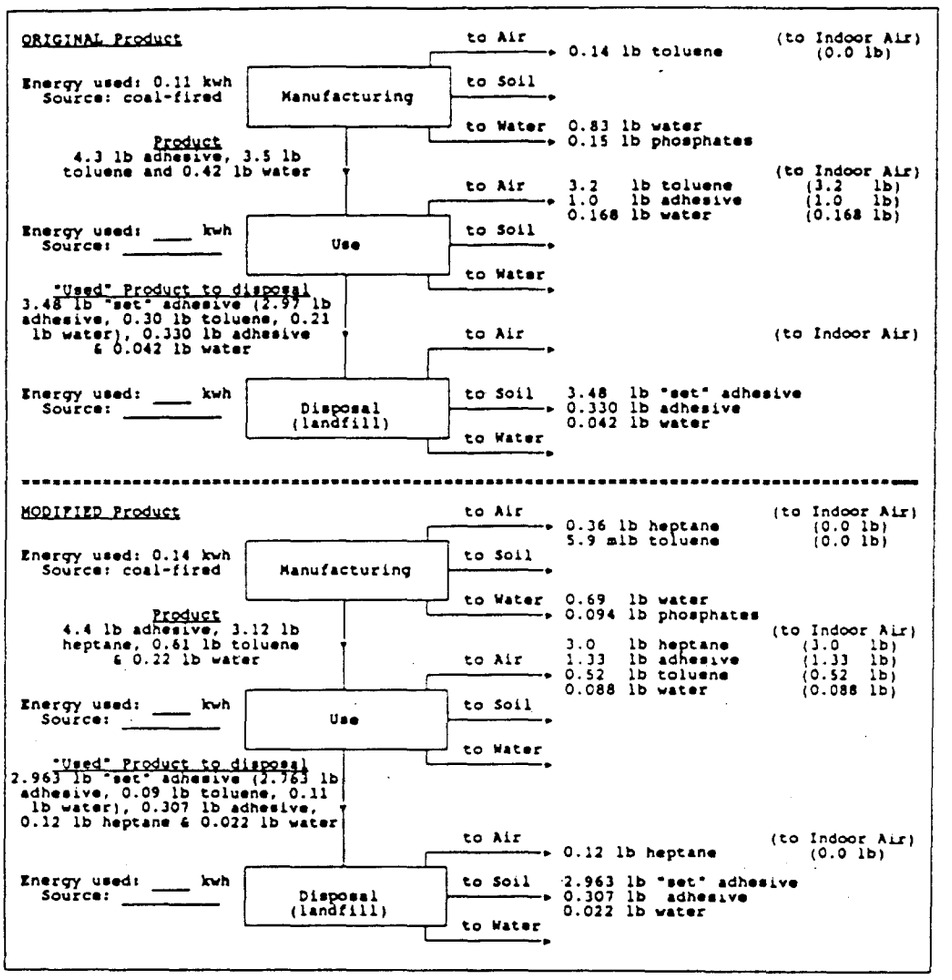


FIGURE 1. Original product and modified product flow sheets for EXAMPLE rubber cement.

the product redesign is adopted. Note once again, however, that this "Mark I" method limits itself to comparing amounts of pollutants prevented, not risks reduced. In a future "Mark II" version, it is envisioned that, within pollutant classes, the "potencies" of various pollutants can be "weighted" so that the resulting summation of, for example, toxic organics, ozone depleters, or biological oxygen demanders, could reflect a more realistic picture of the environmental benefits and detriments the pollution prevention activity would cause. A "Mark III" version could, conceivably, incorporate risk analysis models in such a way that quantified risks and benefits to health and environment could be compared across classes.

The "Pollutants" columns of Table 2 allow examination of the pollution prevented or increased on a pollutant-by-pollutant basis. Note that some of these columns are for specific chemicals, viz., heptane, toluene, water, CO_2, CO and H_2SO_4. Others are for groupings of similar chemicals, viz., phosphates, sulfur oxides and nitrogen oxides. Others are for kinds of pollutants, viz., particulates and solid wastes, while still others are for undefined materials, viz., adhesive and "set" adhesive. This was done deliberately in the example to illustrate that the user has the ability to specify, from a wide variety of types, the pollutants to be examined depending on the information available and the way in which the user desires to have the results expressed.

THE METHODOLOGY

Now, how are data of the type shown in Table 2 to be obtained? As stated above, the approach involves subtracting the amounts of pollution generated by the "modified" product, i.e., with pollution prevention, from the amounts generated by the "original" product, i.e., without pollution prevention. The information required to accomplish this must come from knowledgeable individuals since no measurement methodology can generate this information de novo. The method simply facilitates the manipulation and documentation of this information in a structured way.

Specify Unit-of-Use and Product Life and Document "Assumptions"

First, the product and an appropriate unit-of-use must be specified. For the example, the product is "rubber cement" and the unit-of-use is "1 gallon." Then, the expected product life—the "design life"—of both the original product and the modified product must be defined so that the appropriate comparison of the two products can be made. For rubber cement, a logical product life is "one application" for both the original and the modified formulations. For an automobile

tire, an appropriate "life" might be 40,000 miles. Next, product compositions and appropriate "assumptions" must be documented. This should be done using a format similar to that used for the Example Case shown in Table 1 above.

Select Lifecycle Stages of Interest and Prepare Flow Sheets

A pollution prevention progress evaluation can be made for a single lifecycle stage of a product or for multiple stages, as the user wishes. To facilitate a thorough documentation of the assumptions, original product and modified product lifecycle flow sheets (see Figure 1) should be prepared simultaneously with the assumptions. As can be seen, these flow sheets incorporate mass balances from stage to stage and they denote the specific stage-by-stage "releases" of pollutants into each of the three media and to indoor air if air releases occur inside buildings. In addition to information relating to the generation of pollutants, energy usages and related energy sources should also be recorded on the flow sheets for each lifecycle stage.

It should be emphasized that inclusion of all lifecycle stages during which significant amounts of pollutants are generated can be very important in assessing the real pollution prevention progress associated with a product change. The impacts of pollutants related to the extraction of raw materials or to product manufacture, for example, can often outweigh the environmental concerns surrounding the product constituents themselves. This situation is at the very heart of the on-going "paper vs. plastic" controversy. Such pollutants, therefore, should not often be ignored.

When documenting assumptions, the best data available should be used. In some cases, "before" and "after" measurements can be made. In other cases, "best estimates" or "best engineering judgment" must be applied. Judgments may be required as to the amounts of each pollutant generated, i.e., amounts prior to recycling, treatment or disposal, since pollution prevention progress should reflect source reduction accomplishments, not reductions in releases which result from waste treatment. The user must also make careful decisions as to the media into which each pollutant is or would be discharged. For example, the user must judge that the 0.30 lb toluene which "reacts with the adhesive" in the original product will ultimately be disposed of to a landfill along with that fraction of the adhesive which does not evaporate during use. The user must also recognize that the "half of the water" which "reacts with the adhesive" also must be disposed of and, therefore, "would or could enter the soil/groundwater" when the used rubber cement is finally discarded and that the adsorbed heptane will eventually desorb into the air. These sorts of judgments must be based on the user's knowledge, experience and logical thought.

Product: EXAMPLE rubber cement
Unit-of-Use: 1 gallon (entries are in lb pollutant/Unit-of-Use)

Pollutants related to ORIGINAL Product

ID	Pollutant	Total to Env.	Amt. to Water	Amt. to Soil	Amt. to Air	Amt. to Ind Air
Lifecycle Stage: Manufacturing						
1.	toluene	0.14			0.14	0.0
2.	phosphates	0.15	0.15			
3.	water	0.82	0.82			
Mfg. Total		1.12	0.96	0.0	0.14	0.0
Electric energy, kwh/Unit-of-Use: 0.11 Source: coal-fired						
Thermal energy, MBtu/Unit-of-Use: ___ Source: ___						
Lifecycle Stage: Use						
1.	toluene	1.2			1.2	1.2
5.	adhesive	1.0			1.0	1.0
3.	water	0.168			0.168	0.168
Use Total		4.368	0.0	0.0	4.368	4.368
Electric energy, kwh/Unit-of-Use: ___ Source: ___						
Thermal energy, MBtu/Unit-of-Use: ___ Source: ___						
Lifecycle Stage: Disposal						
6.	"lost" adhesive	1.48		1.48		
5.	adhesive	0.320		0.320		
3.	water	0.042		0.042		
Disposal Total		1.852	0.0	1.852	0.0	0.0
Electric energy, kwh/Unit-of-Use: ___ Source: ___						
Thermal energy, MBtu/Unit-of-Use: ___ Source: ___						
Lifecycle Stage: All Stages						
1.	toluene	1.34			1.34	1.2
2.	phosphates	0.15	0.15			
3.	water	1.048	0.82	0.042	0.168	0.168
4.	heptane	0.0				
5.	adhesive	1.320		0.320	1.0	1.0
6.	"lost" adhesive	1.48		1.48		
All Stages Total		5.348	0.96	1.852	4.508	4.368
Electric energy, kwh/Unit-of-Use: 0.11 Source: coal-fired						
Thermal energy, MBtu/Unit-of-Use: 0.0 Source: ___						

Pollutants related to MODIFIED Product

ID	Pollutant	Total to Env.	Amt. to Water	Amt. to Soil	Amt. to Air	Amt. to Ind Air
Lifecycle Stage: Manufacturing						
1.	toluene	0.0959			0.0959	0.0
2.	phosphates	0.094	0.094			
3.	water	0.69	0.69			
4.	heptane	0.36			0.36	0.0
Mfg. Total		1.1499	0.784	0.0	0.3659	0.0
Electric energy, kwh/Unit-of-Use: 0.14 Source: coal-fired						
Thermal energy, MBtu/Unit-of-Use: ___ Source: ___						
Lifecycle Stage: Use						
1.	toluene	0.12			0.12	0.12
5.	adhesive	1.33			1.33	1.33
3.	water	0.088			0.088	0.088
4.	heptane	2.0			2.0	2.0
Use Total		3.538	0.0	0.0	3.538	3.538
Electric energy, kwh/Unit-of-Use: ___ Source: ___						
Thermal energy, MBtu/Unit-of-Use: ___ Source: ___						
Lifecycle Stage: Disposal						
6.	"lost" adhesive	2.963		2.963		
5.	adhesive	0.307		0.307		
3.	water	0.022		0.022		
4.	heptane	0.12			0.12	0.0
Disposal Total		3.412	0.0	3.292	0.12	0.0
Electric energy, kwh/Unit-of-Use: ___ Source: ___						
Thermal energy, MBtu/Unit-of-Use: ___ Source: ___						
Lifecycle Stage: All Stages						
1.	toluene	0.3259			0.3259	0.12
2.	phosphates	0.094	0.094			
3.	water	0.899	0.69	0.022	0.088	0.088
4.	heptane	2.48			2.48	2.0
5.	adhesive	1.637		0.307	1.33	1.33
6.	"lost" adhesive	2.963		2.963		
All Stages Total		8.4972	0.784	3.292	4.279	3.538
Electric energy, kwh/Unit-of-Use: 0.14 Source: coal-fired						
Thermal energy, MBtu/Unit-of-Use: 0.0 Source: ___						

FIGURE 2. Data tabulation form.

Prepare Data Tabulation Form

On completion of the original product and modified product flow sheets, the medium-by-medium quantities of pollutants generated and the energy usages as taken from the flow sheets are entered on a data tabulation form (see Figure 2). This facilitates the mathematical steps to be taken next.

Perform "Before" Minus "After" Subtractions

Through a series of simple subtractions in which the amount of each pollutant for the modified product is subtracted from the amount of the same pollutant for the original product, either for the total environment or for any given medium, the mass amounts of pollution prevented on a pollutant-by-pollutant and a medium-by-medium basis can be calculated. This can be done for all lifecycle stages combined or on a stage-by-stage basis. The total mass of pollution prevented for each medium or for the total environment can be calculated in much the same way.

For example, from Figure 2, it is seen that the amount of toluene prevented from entering the air during the manufacturing stage is 0.14 lb − 0.0059 lb = 0.1341 lb. The amount of "set" adhesive prevented from entering the soil/groundwater during the Disposal Stage is 3.48 lb − 2.96 lb = 0.52 lb. On the other hand, the amount of heptane prevented from entering the air during product Use is 0.0 lb − 3.0 lb = −3.0 lb. That is, for heptane, the pollution prevented is a *negative* 3.0 lb, viz., an increase of three pounds of heptane entering the atmosphere.

Examination of Figure 2 in concert with Table 2, Part 1, will show that about half of the numbers presented in the first five lines of the Table (the part relating to impacts on the overall environment) can be derived by the relatively simple subtractions described in the above paragraph. Derivation of the remaining numbers involves additional considerations.

Other Considerations

The first relates to the fact that not all substances are pollutants all of the time! In the example, water is released as wastewater during the manufacturing lifecycle stage; water is released as water vapor during use; and liquid water is placed into a landfill during disposal. When thought of in terms of pollutional impact, the water, i.e., the H_2O, that goes either to a waterway or to the air is not a pollutant. Yet, the water that is placed into a landfill will occupy landfill volume and, for purposes of measuring pollution prevention affecting disposal capacity, can be considered a "pollutant." A few other substances require this kind of attention. For example, nitrogen, a natural constituent of the air is not an air pollutant even though it may be released into the air; but carbon dioxide, also a natural air constituent, is considered a pollutant when released to the atmosphere since it contributes to global warming.

The second consideration relates to the fact that the pollutant mass data compiled in Figure 2 does not include the amounts of pollution created as a result of the increased energy required to manufacture the reformulated rubber cement—specifically, 0.03 kwh (0.14 kwh − 0.11 kwh) generated at a coal-fired power plant. Hence, one must include with the pollutant amounts associated with the modified product for the Manufacturing stage, the amounts of the pollutants associated with generating this additional 0.03 kwh of electric energy. From Table 3, it can be calculated that these amounts (for the seven most significant pollutants) are:

CO_2:	2.36	lb/kwh × 0.03 kwh =	0.0708	lb
SO_x:	0.0224	lb/kwh × 0.03 kwh =	0.000672	lb
NO_x:	0.0104	lb/kwh × 0.03 kwh =	0.000312	lb
CO:	0.00367	lb/kwh × 0.03 kwh =	0.0001101	lb
particulates:	0.00435	lb/kwh × 0.03 kwh =	0.0001305	lb
solid waste:	0.306	lb/kwh × 0.03 kwh =	0.00918	lb
sulfuric acid:	0.00199	lb/kwh × 0.03 kwh =	0.0000597	lb
Total:			= 0.0812643	lb

As seen, Table 2, Part 1, includes these energy-related pollutants.

Another aspect to be taken into account relates to the manifestations of air pollution that occur in ambient air but not in indoor air. As discussed above, global warming and smog, for example, occur only in the atmosphere, not in indoor air. Hence, the total pollution prevented for the air medium in this rubber cement example is calculated to be a negative 1.1 lb while the total pollution prevented for indoor air is a positive 2.4 lb (see the first column of Table 2, Part 1). This is due, primarily, to the fact that heptane does have an air impact as both a global warmer and a smog former but is, for this example, not deemed to have any indoor air impact at all. Therefore, the increased release of heptane resulting from the product redesign is added to the impact on air but not to the

Table 3 Largest Pollutant Releases from Various Energy Sources [12]

Electric energy—pounds of pollutant/kilowatt-hour

	Air Pollutants						Solid Waste	Water Pollutants	
Source:	CO_2	SO_x	NO_x	hydro-carbons	CO	partic-ulates	solid waste	dis'lvd solids	H_2SO_4
Coal-fired plant	2.36	0.0224	0.0104	0.000490	0.00367	0.00435	0.306	0.000050	0.00199
Oil-fired plant	2.07	0.0119	0.00521	0.00523	0.000737	0.000618	0.00677	0.00790	0.000024
Gas-fired plant	1.47	0.00104	0.00619	0.0152	0.000726	0.000092	0.00184	0.000119	0.000011
Nuclear plant	0.000129	0.00136	0.000363	—	—	0.000389	0.0613	—	—
Hydroelectric plant	—	—	—	—	—	—	—	—	—
National grid	1.54	0.0135	0.00671	0.00188	0.00217	0.00257	0.187	0.000292	0.00113

Thermal energy—pounds of pollutant/million Btu

	Air Pollutants						Solid Waste	Water Pollutants	
Source:	CO_2	SO_x	NO_x	hydro-carbons	CO	partic-ulates	solid waste	dis'lvd solids	H_2SO_4
Coal combustion	228.	2.49	0.951	0.0461	0.525	0.487	28.3	0.00475	0.187
Oil combustion	194.	0.348	0.185	0.485	0.0690	0.0267	0.596	0.740	0.00223
Gas combustion	134.	0.0955	0.170	1.39	0.0616	0.00846	0.169	0.0109	0.00103

Table 4 Overall Pollution Prevention Progress Achieved per Gallon of Rubber Cement for Each Lifecycle Stage by Pollutant and by Medium

Part 1—For the Manufacturing Lifecycle Stage

Impacts on:	Total	Pollutants: heptane	toluene	adhesive	"set" adhesive	CO_2	phos-phates	water	solid wastes	SO_x	NO_x	partic-ulates	CO	H_2SO_4
Overall Environment	−0.25 lb	−0.36 lb	0.13 lb	—	—	−71 mlb	56 mlb	—	−9.2 mlb	−670 μlb	−310 μlb	−130 μlb	−110 μlb	−60 μlb
Water	56 mlb						56 mlb							−60 μlb
Soil/Groundwater	−9.2 mlb								−9.2 mlb					
Air	−0.30 lb	−0.36 lb	0.13 lb			−71 mlb				−670 μlb	−310 μlb	−130 μlb	−110 μlb	
(Indoor Air)														

Part 2—For the Use Lifecycle Stage

Impacts on:	Total	Pollutants: heptane	toluene	adhesive	"set" adhesive	CO_2	phos-phates	water	solid wastes	SO_x	NO_x	partic-ulates	CO	H_2SO_4
Overall Environment	−0.65 lb	−3.0 lb	2.7 lb	−0.33 lb	—	—	—	—	—	—	—	—	—	—
Water														
Soil/Groundwater														
Air	−0.65 lb	−3.0 lb	2.7 lb	−0.33 lb										
(Indoor Air)	(2.4 lb)		(2.7 lb)	(−0.33 lb)										

Part 3—For the Disposal Lifecycle Stage

Impacts on:	Total	Pollutants: heptane	toluene	adhesive	"set" adhesive	CO_2	phos-phates	water	solid wastes	SO_x	NO_x	partic-ulates	CO	H_2SO_4
Overall Environment	0.44 lb	−0.12 lb	—	23 mlb	0.52 lb	—	—	20 mlb	—	—	—	—	—	—
Water														
Soil/Groundwater	0.56 lb			23 mlb	0.52 lb			20 mlb						
Air	−0.12 lb	−0.12 lb												
(Indoor Air)														

NOTE: Negative numbers signify pollution INCREASES. "mlb" denotes millipounds (1/1,000 lb) and "μlb" denotes micropounds (1/1,000,000 lb). Also, the numbers in Table 4 may sometimes appear not to add correctly since the numbers displayed have been rounded to only two significant figures.

Table 5 Pollutant vs.

Pollutant	CAS No.	Human Health Impacts: Toxic Organic (WSAI)	Toxic Inorg'c (WSAI)	Heavy Metal (WSAI)	Carcino-terato-mutagen (WSAI)	Radio-active (WSAI)	Patho-gen (WSAI)	Fine Fiber (AI)
1. toluene	108-86-3	X						
2. phosphates								
3. water	7732-18-5							
4. heptane	142-82-5							
5. adhesive		X						
6. "set" adhesive								
7. carbon dioxide	124-38-9							
8. solid wastes								
9. sulfur oxides			X					
10. nitrogen oxides			X					
11. particulates								
12. carbon monoxide	630-08-0	X						
13. sulfuric acid	7664-93-9							

W: Pollutant Class has potential impact on Water.
S: Pollutant Class has potential impact on Soil/groundwater.
A: Pollutant Class has potential impact on Air.
I: Pollutant Class has potential impact on Indoor air.

(*Table continued on opposite page*)

impacts on indoor air. It should be pointed out that the method does recognize that pollutants emitted to indoor air eventually become outdoor air pollutants—in using the method, an entry for "Amount to Indoor Air" on Figure 2 may not exceed the corresponding "Amount to Air" entry. Thus, the ambient air pollution impacts from indoor air releases are not ignored—the real point is that indoor air impacts must be tallied separately from atmospheric impacts.

Make the Final Calculations

With these concepts in mind, the Table 2, Part I, figures for the overall environment, can now be derived. To illustrate, the −0.46 lb shown in the table as the total pollution prevention for the overall environment for all three lifecycle stages is obtained in the following way. First, the pollutant-by-pollutant amounts prevented, which are derived through the subtraction of Modified Product, Total To Environment, figures from corresponding Original Product figures as shown in the bottom section of Figure 2, are summed. To illustrate the methodology, the additions and subtractions are carried out using the full numbers from the data tabulation form, but results are rounded to two significant figures. The calculation is:

toluene	3.34	lb −	0.5259	lb =	2.8141	lb ≈	2.8	lb
phosphates	0.15	lb −	0.094	lb =	0.056	lb ≈	56	mlb
water	1.040	lb −	0.800	lb =	0.24	lb ≈	0.24	lb
heptane	0.0	lb −	3.48	lb =	−3.48	lb ≈	−3.5	lb
adhesive	1.330	lb −	1.637	lb =	−0.307	lb ≈	−0.31	lb
"set" adhesive	3.48	lb −	2.963	lb =	0.517	lb ≈	0.52	lb
Sub-total					= −0.1599	lb		

Next, the non-polluting releases prevented, i.e., those consisting of water releases to the water and air media, are subtracted from the above figure. Again from Figure 2, this amounts to (0.83 lb − 0.69 lb) + (0.168 lb − 0.088 lb) = 0.220 lb. The new sub-total is:

$$\text{New sub-total} = -0.1599\ \text{lb} - 0.220\ \text{lb} = -0.3799\ \text{lb}$$

Finally, the amount of energy-related pollution prevented (−0.0812643 lb) is added and the final total is:

$$\text{Final total} = -0.3799\ \text{lb} + (-0.0812643\ \text{lb}) = -0.4611643\ \text{lb} = -0.46\ \text{lb}$$

Note that this number, −0.4611643 lb, should be the sum of all the pollutant amounts presented in the Overall Environment line of Table 2 and that it also should be the sum of the Water, Soil/Groundwater, and Air amounts shown in the Overall Environment section of this Table. Note also, however, that the numbers printed in Table 2 do not sum to exactly this total because each has been rounded to two places (as seen from the calculation above, for example, the 2.8141 lb toluene has been rounded down to 2.8 lb and the 3.48 lb heptane has been rounded up to 3.5 lb).

Just as above, the figures presented in the upper section of Table 2, Part 1, for each non-energy-related pollutant (except water) and for each of the three media, can be obtained by subtracting the amounts for the Modified Product from the corresponding amounts for the Original Product. For water, an adjustment must be made for the fact that its release into water and into air does not count as "pollution." The amount for each energy-related pollutant can be assigned to the appropriate medium as indicated in Table 3.

If the user is interested in the pollution prevention occurring for a particular lifecycle stage, the data in Figure 2 for that stage can be manipulated just as described above to provide the results shown in Table 4.

Classifying Pollutants

The results discussed to this point have dealt only with pollutional impacts on the "overall environment." As described above, however, the method is also capable of segregating these impacts into the three categories—human health impacts, use impairment impacts, and disposal capacity impacts—and also of classifying the pollutants involved so that those causing the same kind of problem can be added together in a reasonably meaningful way. The key to being able to accomplish this is to be able to identify the specific pollutant classes into which each pollutant of concern should be placed. One must also know the media within which each class has its impact so that, for example, fine fibers going to water, a smog former going

Pollutant Class Matrix Assumed for Rubber Cement Example

Pollution Category													
Use Impairment Impacts												Disposal Capacity Impacts	
Particulate (AI)	Global Warmer (A)	Smog Former (A)	Acid Rain Precurs (A)	Ozone Depletr (A)	Odorant (WSAI)	Corrosive (WAI)	Biol. Oxygen Demandr (W)	Chem. Oxygen Demandr (W)	Nutrient (W)	Aquatic Life Toxicnt (W)	Suspn'd Solid (W)	Dis'lvd Solid (WS)	Solid Waste (S)	Haz. Waste (S)
		X			X		X	X						X
									X			X	X	
													X	
	X	X											X	
					X					X				X
													X	
	X													
													X	
			X			X								
	X	X	X			X								
X														
		X												
						X				X		X		X

(*Table continued from opposite page*)

to indoor air or an aquatic life toxicant going to soil are not tallied as pollutants in those media.

From the assumptions listed in Table 1, it is seen that toluene is assumed, for this example, to be a toxic organic, a smog former, an odorant, both a biological and chemical oxygen demander and a hazardous waste. These particular pollutant classes manifest their effects in the various media as shown below.

Pollutant Class	Media in which Impact Can Occur
Toxic Organics	Water, Soil, Air, Indoor Air
Smog Formers	Air
Odorants	Water, Soil, Air, Indoor Air
Biol. O_2 Demanders	Water
Chem. O_2 Demanders	Water
Hazardous Wastes	Soil

This kind of information can be presented in a simple two-dimensional matrix of pollutants vs. pollutant classes. For the rubber cement example case, such a matrix is shown in Table 5. Note that classes are grouped by pollution category and that the media in which each class can have an impact are also indicated.

In using the method, preparation of the above matrix may require library research or consultation to assure that pollutants are classified properly. As will be discussed later, however, a computerized version of the methodology can include this information for a fairly large number of pollutants as a built-in database. Very often, this eliminates the need for the user to develop such a matrix for each pollution prevention technique evaluated.

Results by Pollution Category and by Pollutant Class

With the above matrix in hand, it now becomes a matter of making a series of rather painstaking calculations to develop the remainder of the entries presented in Table 2. For example, the amounts of pollution prevented for the Human Health Impact category can be determined as can the amounts prevented for the other two categories. The total and the pollutant-by-pollutant human health-impacting pollution prevented during all three lifecycle stages, as shown in the first line of the second section of Part 1, result from the subtraction of the amounts of now-identified health-impacting pollutants for the Modified Product from the corresponding numbers for the Original Product. The now-known, health-impacting, energy-related pollutants are also included. These amounts are:

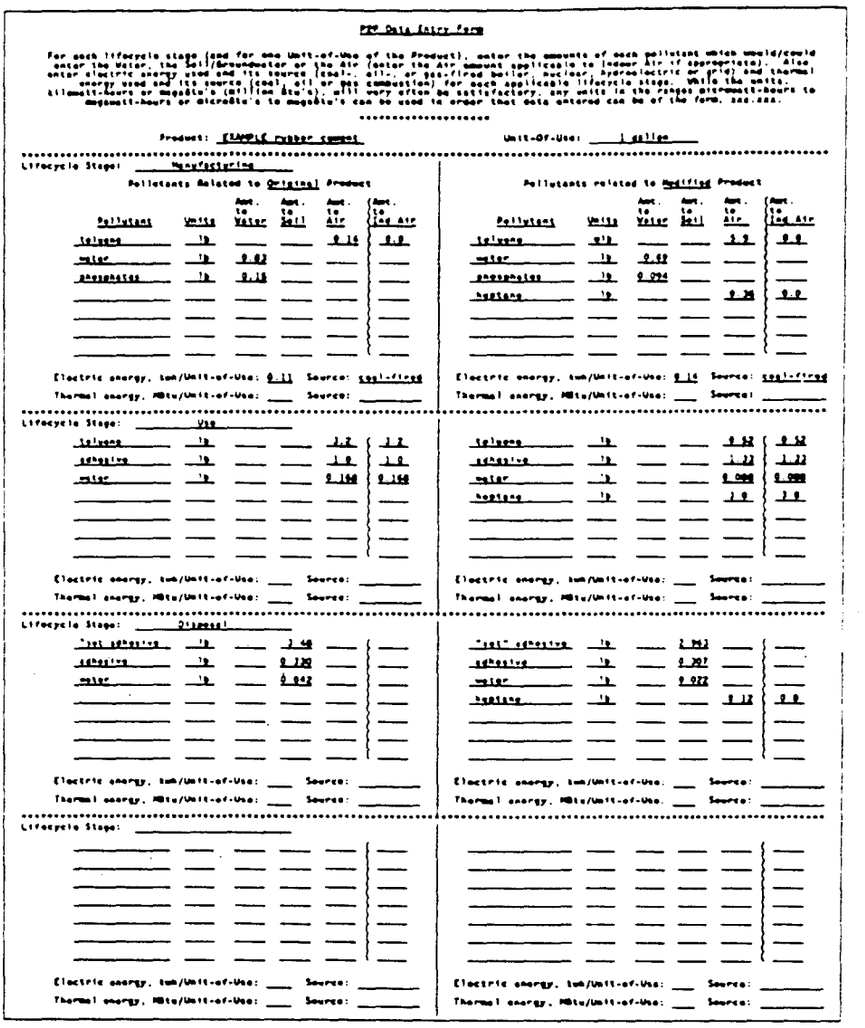
toluene	3.34 lb − 0.5259 lb =	2.8141	lb =	2.8 lb
adhesive	1.330 lb − 1.637 lb =	−0.307	lb =	−0.31 lb
SO_x		−0.000672	lb =	−670 μlb
NO_x		−0.000312	lb =	−310 μlb
CO		−0.0001101	lb =	−110 μlb
Total	=	2.5060059	lb =	2.5 lb

The amounts presented in Table 2, Part 1, for medium-by-medium pollution prevention are calculated in similar fashion. For example, the pollution increase of 0.33 lb of adhesive in Air within the Use Impairment Category is obtained by subtracting 1.33 lb from 1.0 lb. These figures are found in the All Stages section of Figure 2, "Amount to Air" columns.

The results presented in Table 2, Part 2, are obtained in the same way, this time using the pollutant vs. pollutant class matrix, Table 5, to determine which pollutants to tabulate together when performing the "before pollution prevention minus after pollution prevention" subtractions. To illustrate, the increase of 0.67 lb of "smog formers" resulting from the rubber cement reformulation involves 1) identifying from Table 5 that the smog formers are heptane, toluene, NO_x and CO, 2) determining from Figure 2 which emissions of these pollutants go to the outside air, 3) summing the amounts of these particular pollutants released before and then after the reformulation and, finally, 4) subtracting the "after" total from the "before" total for each pollutant and for all of them as a group. The calculation is:

toluene	3.34 lb − 0.5259 lb =	2.8141	lb =	2.8 lb
heptane	0.0 lb − 3.48 lb =	−3.48	lb =	−3.5 lb
NO_x		−0.000312	lb =	−310 μlb
CO		−0.0001101 lb	=	−110 μlb
Total Smog Formers prevented	=	−0.6663221	lb =	−0.67 lb

One can see that similar calculations will produce pollution prevention data on a "lifecycle stage-by-lifecycle stage" basis if desired.



P2P Data Entry Form

For each lifecycle stage (and for one Unit-of-Use of the Product), enter the amounts of each pollutant which would/could enter the Water, the Soil/Groundwater or the Air (enter the Air amount applicable to Indoor Air if appropriate). Also enter electric energy used and its source (coal-, oil-, or gas-fired boiler, nuclear, hydroelectric or grid) and thermal energy used and its source (coal, oil or gas combustion) for each applicable lifecycle stage. While the units, kilowatt-hours or megaWatt's (million Btu's), will very often be satisfactory, any units in the range gigawatt-hours to megawatt-hours or microBtu's to megaBtu's can be used in order that data entered can be of the form, xxx.xxx.

Product: EXAMPLE rubber cement Unit-Of-Use: 1 gallon

Lifecycle Stage: Manufacturing

Pollutants Related to Original Product

Pollutant	Units	Amt. to Water	Amt. to Soil	Amt. to Air	Amt. to Ind Air
toluene	lb			0.14	0.0
water	lb	0.02			
phosphates	lb	0.18			

Electric energy, kwh/Unit-of-Use: 0.11 Source: coal-fired
Thermal energy, MBtu/Unit-of-Use: ___ Source: ___

Pollutants related to Modified Product

Pollutant	Units	Amt. to Water	Amt. to Soil	Amt. to Air	Amt. to Ind Air
toluene	g/lb			5.0	0.0
water	lb	0.02			
phosphates	lb	0.094			
heptane	lb			0.36	0.0

Electric energy, kwh/Unit-of-Use: 0.14 Source: coal-fired
Thermal energy, MBtu/Unit-of-Use: ___ Source: ___

Lifecycle Stage: Use

Pollutant	Units	Amt. to Water	Amt. to Soil	Amt. to Air	Amt. to Ind Air
toluene	lb			1.2	1.2
adhesive	lb			1.0	1.0
water	lb			0.160	0.160

Electric energy, kwh/Unit-of-Use: ___ Source: ___
Thermal energy, MBtu/Unit-of-Use: ___ Source: ___

Pollutant	Units	Amt. to Water	Amt. to Soil	Amt. to Air	Amt. to Ind Air
toluene	lb			0.52	0.52
adhesive	lb			1.23	1.23
water	lb			0.080	0.080
heptane	lb			1.0	1.0

Electric energy, kwh/Unit-of-Use: ___ Source: ___
Thermal energy, MBtu/Unit-of-Use: ___ Source: ___

Lifecycle Stage: Disposal

Pollutant	Units	Amt. to Water	Amt. to Soil	Amt. to Air	Amt. to Ind Air
"wet" adhesive	lb		1.40		
adhesive	lb		0.120		
water	lb		0.042		

Electric energy, kwh/Unit-of-Use: ___ Source: ___
Thermal energy, MBtu/Unit-of-Use: ___ Source: ___

Pollutant	Units	Amt. to Water	Amt. to Soil	Amt. to Air	Amt. to Ind Air
"wet" adhesive	lb		2.943		
adhesive	lb		0.207		
water	lb		0.072		
heptane	lb			0.12	0.0

Electric energy, kwh/Unit-of-Use: ___ Source: ___
Thermal energy, MBtu/Unit-of-Use: ___ Source: ___

Lifecycle Stage: ___

Electric energy, kwh/Unit-of-Use: ___ Source: ___
Thermal energy, MBtu/Unit-of-Use: ___ Source: ___

Electric energy, kwh/Unit-of-Use: ___ Source: ___
Thermal energy, MBtu/Unit-of-Use: ___ Source: ___

FIGURE 3. P2P data entry form.

P2P—THE COMPUTERIZED VERSION

It is recognized that the data storage and data manipulation involved in applying this methodology would be both cumbersome and time-consuming. Hence, it is immediately apparent that a computerized version is needed to facilitate practical application. A computer can perform all of the sorting and mathematical steps required and, as well, could provide "instant access" to a database containing a pollutant vs. pollutant class matrix.

Such a software program, dubbed "P2P" for Pollution Prevention Progress, has been written. The 500-kilobyte program, written in CA-Clipper, is for use on DOS-based PCs. It allows the user to select either a pollution prevention mode, i.e., application of the method described above, or a pollution generated mode, i.e., a documentation of the pollution associated with a particular product in terms of the media affected and the applicable impact categories and pollutant classes.

How It Works

The user of P2P is prompted to enter the product name, a suitable unit-of-use, a product life, and the product lifecycle stages of interest. The "assumptions" must, of course, be documented as illustrated in Table 1 and then translated onto suitable lifecycle flowsheets as depicted in Figure 1. A P2P Data Entry Form is then prepared. Figure 3 shows this form containing the input data for the rubber cement example described above.

Once this is done, the user enters the data from the data entry form into P2P. For those pollutants that may already be in P2P's pollutant vs. pollutant class database, no classes need be assigned unless the user wishes to alter the classes previously indicated as applicable. For other pollutants, the user is prompted to select the classes that apply to each.

How Pollution Prevention Progress Is Reported

When data entry is complete, the program will produce any of seven different reports for all of the selected lifecycle stages for the product, for any single stage, or for any desired combination of stages. P2P's reports automatically exclude inappropriate data such as for water vapor released to the air. P2P matches class information for a pollutant with the media into which the pollutant is or would be released and omits

mention of, for example, an aquatic life toxicant not released to water or a smog former released to indoor air. Finally, P2P automatically generates and includes in its reports any energy-related pollutant releases. There are three basic report formats:

Format A—Pollution Prevention (or Generated) by Pollution Category and by Medium — Report 1

Format B—Pollution Prevention (or Generated) by Pollution Category, by Pollutant, and by Medium — Report 2

Format C—Pollution Prevention (or Generated) by Pollution Category, by Pollutant Class, and by Pollutant for the Overall Environment or for any single medium, including Indoor Air — Reports 3 through 7

Sample copies of each of the three kinds of reports for the rubber cement example are shown in Table 6—Format A for all selected lifecycle stages combined, Format B for the Use stage alone, and Format C for air pollution prevented for the Use and Disposal stages combined. The Format A report provides exactly the same information as does column 1 of Table 2, Part 1. The Format B report, on the other hand, looks only at the "Use" lifecycle stage. It highlights the facts that, during this stage, 1) only air pollution and indoor air quality are impacted by the rubber cement reformulation, 2) the impacts on air and indoor air are different since heptane does not impact indoor air and 3) there is no disposal capacity impact. The Format C report allows one to examine impacts on air pollution alone when two of the three lifecycle stages, Use and Disposal, are looked at together. It delineates which specific pollutants cause the impacts in the various classes.

Table 6 Examples of P2P Report Formats

Product: EXAMPLE rubber cement
Unit-of-Use: 1 gallon
Orig/Mod Prod Life: 1/1 application

Pollution Prevention Progress per Unit-of-Use of product

Format A: By Pollution Category and by Medium—for all three Lifecycle Stages

Pollution prevented for:	All Media	Water	Soil/ Grdwater	Air	(Indoor Air)
Overall environment	−0.46 lb	56. mlb	0.55 lb	−1.1 lb	(2.4 lb)
Human health impacts	2.5 lb		23. mlb	2.5 lb	(2.4 lb)
Use impairment impacts	−0.99 lb	56. mlb	23. mlb	−1.1 lb	(2.4 lb)
Disposal capacity impacts	0.55 lb		0.55 lb		

Format B: By Pollution Category, by Pollutant and by Medium—for "Use" Stage

Pollution prevented for:	All Media	Water	Soil/ Grdwater	Air	(Indoor Air)
Overall environment	−0.65 lb			−0.65 lb	(2.4 lb)
adhesive	−0.33 lb			−0.33 lb	(−0.33 lb)
heptane	−3.0 lb			−3.0 lb	( )
toluene	2.7 lb			2.7 lb	(2.7 lb)
Human health impacts	2.4 lb			2.4 lb	(2.4 lb)
adhesive	−0.33 lb			−0.33 lb	(−0.33 lb)
toluene	2.7 lb			2.7 lb	(2.7 lb)
Use impairment impacts	−0.65 lb			−0.65 lb	(2.4 lb)
adhesive	−0.33 lb			−0.33 lb	(−0.33 lb)
heptane	−3.0 lb			−3.0 lb	( )
toluene	2.7 lb			2.7 lb	(2.7 lb)
Disposal capacity impacts NONE					

Format C: By Pollution Category, by Pollutant Class and by Pollutant for Air—for the "Use" and "Disposal" Stages Combined

Pollution Category	Pollutant Class	Amount Prevented	Pollutant	Amount Prevented
Human health impacts	Toxic Inorganics	2.4 lb		
			adhesive	−0.33 lb
			toluene	2.7 lb
Use impairment impacts	Global warmers	−3.1 lb		
			heptane	−3.1 lb
	Odorants	2.4 lb		
			adhesive	−0.33 lb
			toluene	2.7 lb
	Smog formers	−0.44 lb		
			heptane	−3.1 lb
			toluene	2.7 lb

Note: In these reports, negative numbers signify pollution INCREASES. Also, some totals may appear incorrect since all numbers displayed have been rounded to two significant figures.

Pollutant Class Information Is Needed

While users of this method can be expected to make reasonable estimates of or be able to measure the pollutants associated with a product and their media fates, they very often will not have ready access to information on the applicable pollutant classes for each pollutant. P2P calls for such data to be entered. The typical user will not be highly knowledgeable as to the wide variety of effects an individual pollutant may exhibit. Yet, such pollutant class information is essential in order for P2P to generate its output reports. This may require library research or advice of a knowledgeable consultant.

A database reflecting pollutant vs. pollutant class information of the type shown in Table 5 is currently under development as an adjunct to P2P. The database, which can be incorporated into the P2P software, will contain Class information on some three or four hundred chemicals. In essence, the database will reflect a judgment as to whether, for example, a given pollutant is or is not a toxic organic, a global warmer or a biological oxygen demander. It is recognized that many of these judgments have to be arbitrary since, as mentioned above, for most pollutant classes there is a range of "potencies" of the pollutants which may be considered to fall within a class. The Mark I software allows individual users to modify and update existing pollutant class information to reflect their own judgments or as they may otherwise deem appropriate. In the Mark II version, the user will also be free to add additional classes which may be of particular interest.

CONCLUSIONS

This "Mark I" methodology is not "profound" and clearly is not meant to be a final pollution prevention progress measurement methodology that will answer all questions concerning pollution prevention progress for all circumstances. Rather, it is an attempt to lay out, in an orderly fashion, a conceptual approach to measuring or estimating the pollution prevention progress which can be attributed to the conduct of some pollution prevention action—in this case, a product re-design or reformulation. The method takes into consideration all of the individual chemicals or materials affected, it takes into account the increases in generation of some pollutants when others are being reduced, it allows for summation of different "classes" of pollutants, and it relates prevention to the specific media that would or could be impacted by the action.

The method does not, however, attempt to relate quantities of pollutants reduced to the related reductions of various health and/or environmental risks even though this is a desirable ultimate step at some point in the future. One can conceive of moving toward this goal, at least initially, by the use of appropriate "potency weightings" assigned to individual pollutants before their impacts are added together. Ultimately, however, the relatively complex methods associated with making risk assessments will need to be applied.

It is recognized that many products are quite complex and are composed of many parts. To deal with this complication, perhaps products having only roughly 10 or 15 components or less should be tackled directly by the method and products of greater complexity handled by considering them to be made up of less complex sub-parts. An automobile, for example, would not have to be assessed as a single product but rather, its sub-parts, engine, frame, tires, battery, etc., could each be assessed separately. The impact of design changes for a whole automobile could then be determined by summing up the impacts of the changes in its parts.

The conceptual methodology outlined here should lend itself, with minor modifications, to use for other types of pollution prevention projects than product redesign/reformulation. In fact, with a little imagination one can see applications to *any* "before" and "after" situation, e.g., "before treatment" and "after treatment" or even "before regulation" and "after regulation." Subtracting the "after" data from the "before" data, relating these differences to individual chemicals, to pollutant classes, to health impacts, use impairment impacts and other impacts and to the media affected should be readily possible.

It is hoped that this methodology, even in its relatively crude initial form, can be used to assist decision makers in their responsibilities concerning whether to implement individual pollution prevention projects and to help them assess the progress made from past actions. The overview of environmental gains and losses which the methodology provides should be helpful in this regard.

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FEASIBILITY ANALYSIS

TABLE 3
EXAMPLE SEMI-QUANTITATIVE ANALYSIS SCORE SHEET

Criteria	*Criteria weight*	*Project 1*[1]		*Project 2*[2]		*Project 3*[3]	
		Score	*Weighted score*[4]	*Score*	*Weighted score*[4]	*Score*	*Weighted score*[4]
Waste/Release							
Toxicity	4	1	4	3	12	1	4
Persistence	3	1	3	3	9	1	3
Concentration	2	1	2	1	2	1	2
Odor	5	3	15	1	5	1	5
Visibility	3	1	3	1	3	1	3
Volume	2	1	2	2	4	3	6
Regulatory status	3	3	9	2	6	2	6
Management method							
Degree of control	4	3	12	1	4	2	8
Permanence	4	3	12	2	8	1	4
Degree of treatment	3	3	9	3	9	1	3
Regulatory status	3	3	9	2	6	1	3
Medium discharged to							
Dispersion/dilution	2	1	2	3	6	1	2
Current condition	4	2	8	3	12	2	8
Local use	4	1	4	2	8	2	8
Known impacts	3	3	9	1	3	2	6
Regulatory status	2	1	2	1	2	1	2
Reduction method							
Permanence	1	3	3	3	3	3	3
Point of reduction	1	2	2	2	2	2	2
Environmental impact	2	3	6	3	6	3	6
Regulatory status	3	3	9	3	9	1	3
Community							
Proximity	1	3	3	3	3	3	3
Level of interest	4	3	12	1	4	1	4
Current relations	3	1	3	1	3	1	3
Concern over waste/release	5	3	15	1	5	1	5
Perceived toxicity	5	2	10	1	5	1	5
TOTAL WEIGHTED SCORE			168		139		107

[1]Elimination of an uncontrolled, periodic process gas emission that has an objectionable odor.

[2]Reduced generation of a hazardous waste that is currently disposed in an onsite landfill.

[3]Reduced wastewater generation and discharge.

[4]Criteria weight multiplied by the score.

Source: E. Hillenbrand et al.

quirements) to select the most appropriate alternative.

Probabilistic Analysis

Probabilistic analysis provides a dollar estimate of indirect benefits and estimates when those benefits may occur. The results are designed to be incorporated into a net present value analysis.

This approach is appropriate only if the following factors can be estimated with some certainty:

- Dollar value of potential indirect benefits.
- Future date(s) when benefits will be realized.
- Probability that benefits will be realized, and
- Percent contribution of the waste minimization alternative to the benefits obtained.

In performing a probabilistic analysis, the costs associated with the current waste management scheme are evaluated first using the following steps:

1. Calculate the projected cash flow based on known costs and revenues, if any. This calculation should include costs of offsite treatment/disposal, onsite management, recordkeeping, and administration/overhead.

2. Estimate potential future liability and compliance costs associated with the current practice, probability that the costs will be incurred, and the time at which the costs will be incurred. Potential liabilities may be estimated based on the company's past experience or by using a method developed by General Electric. The method is described in a workbook entitled *Financial Analysis of Waste Management Alternatives*, GE Corporate Environmental Programs, Stamford, CT, 1987. It is summarized in the March/April 1988 issue of *The Hazardous Waste Consultant* beginning on page 1-1. Potential compliance costs can be estimated by analyzing proposed legislation and regulations.

3. Calculate the expected monetary value (EMV), where EMV = future liability and compliance costs x probability of occurrence, and incorporate it into the projected cash flow.

Next, the costs associated with the waste minimization project are calculated:

1. Determine the estimated cash flow for the minimization project.

2. Estimate potential future revenues, probability that the revenues will be realized, contribution of the project to obtaining the revenues, and time when the revenues will be realized.

3. Calculate the EMV, where EMV = revenue x probability x percent contribution, and incorporate it into the estimated cash flow for the minimization project.

The net cash flow for the minimization project can then be calculated by subtracting the current waste management scheme cash flow from the minimization project cash flow. The net present value (NPV) of the net cash flow can then be calculated. A negative value indicates a cost, while a positive value indicates a revenue. The higher the NPV, the more attractive the alternative.

Finally, NPVs for each minimization alternative are evaluated along with other factors (e.g., technical feasibility, product quality impacts, labor requirements, process compatibility, space availability, reliability, and utility requirements) to select the most appropriate project.

Conclusions

The authors indicate that the semi-quantitative method of comparing indirect benefits is probably the most useful. It does not require as much data as the probabilistic method and can be used to evaluate alternatives quickly and inexpensively. With minor changes, the method can also be used to determine minimization priorities by ranking wastes and releases based on their characteristics and management methods.

Due to the large amount of effort involved, probabilistic analysis may only be justified in situations where the alternatives entail large capital investments.

DryPure™ Technolog Converts Sludges to Powder

A new technology that dries pain to an inert powder is now availa Haden Environmental Corporation Michigan). The volume of powder p by the DryPure™ process is about o the original sludge volume. The tec may also be used to treat other mater are too sticky for conventional methods (e.g., printing inks, adhesiv vent recovery sludges, oil refinery and paper mill wastes). However, th rials must be reducible to dry for temperature less than 450°F (235° must not contain non-friable material than 1 inch (2.5 cm) in diameter.

The DryPure™ Process

The DryPure™ system, which wa nally developed to treat paint sludg automotive assembly plants, consist oil-heated sludge dryer and an offgas incinerator. During processing, paint are progressively heated in the modifi low screw sludge dryer, which is desi prevent fouling by sticky materials a tains an oxygen-free atmosphere the potential for fire or explosion. the sludge is heated at low temperat drive off volatile hydrocarbons and m and cure residual paint resins. After th place, the temperature is increased to (148°C) to ensure thorough drying. exiting the dryer is screened or sie separate dried paint powder from m that has not been completely process adequately dried material is returned dryer for re-processing.

Offgases are collected and treated thermal incinerator to destroy volat ganic compounds. Heat from the inci is recovered by the sludge dryer. believes that only New Source Perfor Standard air emission permits will pr be required for the incinerator at most ties. Hazardous waste incineration p are not likely to be required since on gases are incinerated.

The powder produced by the Dry process is inert and insoluble. Ac Haden, paint sludges tested to da been hazardous due to the toxicity c

Krishna

As part of the Waste Reduction Evaluations at Federal Sites (WREAFS) program, EPA promotes waste minimization research opportunities and technical assessments at federal facilities. This report details the outcome of a waste reduction assessment performed at a U.S. Army base in Fort Riley, Kansas where automotive maintenance programs generate hazardous wastes. Recycling options that were identified include 1) filtering, restrengthening, and recycling waste battery acid, and 2) purifying and reusing alkaline detergent solution. Implementation of the options was estimated to result in annual cost savings of $143,000/year, with payback periods ranging from two to five months.

Evaluating Pipeline Leak Detection Systems

"Standard Test Procedure for Evaluating Pipeline Leak Detection Systems" (EPA/600/2-90/050), by Joseph W. Maresca, Jr. et al. (Vista Research, Inc., Mountain View, California), July 1990, $23 paper copy, $23 microfiche, NTIS order number: PB91-106245/AS.

Federal regulations require that pipelines associated with underground storage tanks be equipped with leak detection systems that monitor for leaks on a regular basis. EPA has developed a standard test procedure to be used to evaluate the performance of different leak detection systems against the standards set by EPA in 40 *CFR* Part 280, Subpart D. Specifically, the procedure covers the following internal leak detection methods: an hourly test, a monthly monitoring test, and an annual line tightness test. The test procedure, outlined in a 13-step process, can be used to evaluate any system attached to a pipeline that measures or monitors either flow rate or changes in pressure or product volume.

Comment: The reports listed above can be ordered from the National Technical Information Service (NTIS), U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161, (703) 487-4650.

WASTE MINIMIZATION CASE STUDIES

Economic Analysis of Waste Minimization Projects: Methods for Comparing Indirect Benefits

Waste minimization projects are usually selected based on capital cost, operating cost, and direct benefits, such as disposal and raw material cost savings. Indirect benefits (e.g., avoidance of future liability, improved community relations, etc.) are more difficult to estimate and therefore are rarely considered.

Two methods for incorporating indirect benefits into the economic analysis of waste minimization alternatives have been described by Eric Hillenbrand of Ernst & Young, Inc. (Washington, DC) and Terry Casey of N.L. Industries, Inc. (Houston, TX). Their paper, entitled "Decision Analysis for Waste and Chemical Release Reduction Projects: Selecting Optimal Projects Considering Direct and Indirect Benefits," appears in *Proceedings of HMC Great Lakes 90*. The proceedings are available from the Hazardous Materials Control Research Institute, 9300 Columbia Boulevard, Silver Spring, Maryland 20910-1702, (301) 587-9390, $54 (shipping included).

Indirect Benefits

Indirect benefits are uncertain future monetary advantages that may result from a waste minimization project. They include:

- Avoiding future liability costs for potential remedial actions at onsite and offsite treatment, storage, or disposal facilities.
- Avoiding potential costs of complying with future regulations.
- Revenues from sale of pollution credits or offsets.
- Revenues from internal use of pollution credits or offsets on new projects/future plant expansions.
- Improved community relations that result in monetary savings. For example, a facility may find it easier and quicker to obtain a zoning variance for a major expansion if it has a good relationship with the surrounding community. Goodwill can be fostered by reducing releases or emissions that the residents object to.
- Revenues from licensing or sale of proprietary waste/release minimization methods that may have broad applicability within the industry.
- Increased sales to environmentally conscious customers who prefer suppliers that minimize wastes and emissions.

The indirect benefits of waste minimization alternatives can be compared using semi-quantitative or probabilistic analysis methods, both of which are discussed below.

Semi-Quantitative Analysis

Semi-quantitative analysis compares the indirect benefits of waste minimization alternatives by assigning relative judgment-based scores to each alternative. The scores are then analyzed in conjunction with the results of a standard economic analysis to select the most appropriate alternative.

The steps in performing a semi-quantitative analysis are:

1. Select the criteria that will be used to rate indirect benefits. Example criteria are presented in Table 1 (page 1.20).
2. Assign a weight to each criterion based on its relative importance in contributing to potential benefits. For example, in the case of air emissions, odor will probably be more important than reduction method when assessing benefits to community relations. Weights may range from 1 (low importance) to 5 (high importance).
3. Determine the scale that will be used for scoring. The authors use a scale of 1 to 3 with higher scores indicating more significant potential benefits. For the odor criterion, a waste/release with no odor would receive a score of 1, while a waste/release with a highly objectionable odor would be assigned a 3. This reflects the fact that reduction of more odoriferous wastes/releases would produce greater benefits.

TABLE 1
EXAMPLE CRITERIA FOR A SEMI-QUANTITATIVE ANALYSIS OF INDIRECT BENEFITS

Waste/Release
- Toxicity
- Persistence
- Mobility
- Concentration
- Odor
- Visibility
- Volume
- Regulatory status

Current management method
- Degree of control over release
- Permanence of control
- Degree of reduction in:
  - Toxicity
  - Mobility
  - Persistence
- Regulatory status

Medium discharged to
- Dispersion/dilution potential
- Current condition
- Regulatory status
- Local use
- Known or suspected impacts

Reduction method
- Permanence
- Point of reduction
- Environmental impacts
- Regulatory status

Community
- Proximity to facility
- Level of interest
- Current status of commur relations
- Concern over waste/release
- Perceived toxicity/threat

Source: E. Hillenbrand et al.

TABLE 2
EXAMPLE SCALES FOR SELECTED CRITERIA

Criteria	*Scoring scale*		
	1	*2*	*3*
Waste/Release			
Toxicity	None or low	Moderate	High
Odor	None or low	Strong & neutral, or faint & unpleasant	Strong & unpleasant
Current management method			
Degree of control	Highly controlled	Partial control	Uncontrolled
Permanence of control	Permanent	10-20 years	<10 years
Medium discharged to			
Dispersion/dilution potential	High, dynamic	Medium	Low, static
Current condition	Good, no use restrictions	Moderately degraded, some restrictions	Pristine or highly degraded
Reduction method			
Point of reduction	Post-process	Recycle back to process	Eliminated in process
Community			
Proximity	>3 miles	1-3 miles	<1 mile
Perceived toxicity	No perception	Moderately toxic	Highly toxic

Source: E. Hillenbrand et al.

Table 2 provides example sc several criteria.

4. For each alternative, compile basi mation on wastes/releases, curre agement methods, proposed re methods, and community concer information will be used during sc

5. Score each alternative for each according to the appropriate s Hillenbrand et al. recommend that be performed by a workgroup t upon the knowledge and expertise familiar with the waste or release, management practices, regulato mate, and community relations.

6. Multiply the score for each criterior criterion weight to generate a we score.

7. Sum the scores for each alternative. 3 shows how three hypothetical minimization projects would be sco an odor reduction project, 2) a r hazardous waste generation/dispos ject, and 3) a reduced wastewater g tion/discharge project.

8. Compare the summed scores in co tion with other economic analysis mation (e.g., net present value, tec feasibility, product quality impacts, requirements, process compat liability, space availability, and

teristic. Heavy metals, such as lead and chromium, are sealed into the cured resin and therefore their leachability is minimal.

DryPure™ powder can be recycled as a substitute for fillers in paint, mastics, plastics, sealants, and rubber products. It can also be used as a bulk fuel in coal-fired boilers, cement kilns, and other systems suitable for burning powders. The powder typically has a fuel value of about 9,000 BTU/lb (21,000 kj/kg).

Full-Scale Operations

A full-scale DryPure™ system has been in operation at an automotive assembly plant near Detroit since September 1988. The system, which operates two shifts per day, handles up to 2,300 lb/hr (1,040 kg/hr) wet sludge (20% solids) and produces 2,000 lb (907 kg) dry powder per day. This represents a 90% reduction by weight.

Contact Information

For additional information on the DryPure™ paint sludge drying system, contact Mr. Nicholas Bailey, Sales Manager, Haden Environmental Corporation, 1460 Rankin Drive, Troy, Michigan 48084, (313) 585-5790.

Westinghouse Waste Minimization Program Gets Results

Westinghouse Electric Corporation has created a corporate program to reduce hazardous and solid wastes, air emissions, wastewater discharges, and employee exposures. To date, the Achievements in Clean Technologies (ACT) program has been successful in minimizing wastes/discharges from several operations, including metal working, electroplating and metal finishing, spray painting, and laminate production.

Minimization projects implemented by the ACT program are described by Dan Wesolowski and Tim Rumon of Westinghouse in their paper entitled "The Westinghouse ACT Program: Waste Minimization Success Stories." The paper is published in *Conference Proceedings of Haztech International 90, October 2-4, 1990, Pittsburgh, Pennsylvania*. The proceedings are available from Haztech International, 13555 Bell-Red Road, Bellevue, Washington 98009, (800) 468-7644, $89 (shipping included).

Minimizing Cutting Fluids

Several types of metal working operations (e.g., shearing, punching, bending, machining, grinding, welding, and forming) take place at Westinghouse facilities. During these activities, cutting fluids are used for heat dissipation, lubrication, chip and particle removal, and corrosion protection. Lubricating oils and hydraulic oils are also used.

Although spent cutting fluid is not considered a hazardous waste in many states, Westinghouse decided to target it for minimization due to the large quantities generated. Two facilities where the company has begun cutting fluid management and recycling programs are discussed below.

80% Waste Reduction in Florida

In 1987, Westinghouse instituted a cutting fluid management and recycling program at a large machining/manufacturing facility in Florida. As part of the program, the plant first converted from a central cutting fluid system (where all machines discharged cutting fluid to a single sump) to a decentralized system that allowed the plant to segregate different cutting fluid types. Then, a high-speed centrifuge was installed to remove unwanted lubricating oils, hydraulic fluid, and debris from the waste cutting fluid. The clean cutting fluid produced by the centrifuge is now reused. A new mixing system insures that the proper recycled cutting-fluid-to-water ratio is consistently delivered to the equipment. Complete cutting fluid change out and recycle from each machine occurs every 20 days.

Finally, the facility began mixing cutting fluids with deionized water to increase their performance. Cutting fluids mixed with tap water can contain high levels of metals, bacteria and other compounds that leave residues on recovery system equipment and decrease cutting fluid life.

By implementing these improvements, the volume of waste sent offsite for disposal was reduced by about 80%. In addition, the nature of the waste changed from primarily water to primarily oil, increasing its offsite recycling value.

Six-Month Payback in North Carolina

A similar minimization project was implemented in 1988 at a Westinghouse manufacturing facility in North Carolina. At that time, the plant generated 500,000 gallons of spent cutting fluid a year. During the minimization project, the facility has:

- Installed oil skimmers on all machine cutting fluid reservoirs to remove free oil. Oil promotes biological activity and shortens cutting fluid life. Machine operators were also trained to maintain a constant cutting fluid concentration. These activities reduced waste cutting fluid by 26% (130,000 gal/yr).
- Segregated waste cutting fluid and waste oil streams to allow the oils to be recycled.
- Consolidated the number of different cutting fluids used at the plant to make recycling more attractive.
- Recycled cutting fluid with a pasteurizer and coalescer. The recycled cutting fluid is automatically maintained at the proper concentration by adding water or cutting fluid concentrate.
- Installed evaporators to eliminate most of the water from the waste cutting fluid. The remaining fluid (about 50,000 gal/yr) is disposed offsite as high-BTU feedstock for fuel blending.

Implementing these improvements reduced the volume of waste cutting fluid by 90% (from 500,000 gal/yr to 50,000 gal/yr).

The total capital cost for the project was $140,000 and the yearly operating cost savings were about $290,000. Therefore, the equipment payback period was less than 6 months.

Electroplating and Metal Finishing Operations

Westinghouse has modified several electroplating/metal finishing operations to reduce wastes/emissions generated by solvent degreasers, dragout, and wastewater treatment. Several examples are provided below.

Minimizing Degreasing Wastes

At a facility in Puerto Rico, Westinghouse

initiated several equipment modifications and changed operating practices to minimize emissions/wastes from two vapor degreasers used to clean metal parts. As part of the minimization program, the plant:

- Covered the boiling sump to reduce solvent emissions,
- Increased the freeboard area (distance between the primary cooling coil and the top of the unit),
- Installed sump cool-down coils to lower solvent temperatures during off hours and thereby reduce evaporation,
- Installed variable-speed controls for lip exhaust to reduce evaporation during degreaser idle time,
- Reduced conveyor speed to avoid vapor displacement,
- Retrofitted the carrier rack to reduce solvent dragout and vapor displacement,
- Installed sump bottom filtration units and new water separator units to clean the solvent and therefore increase its life,
- Operated degreasers only as required instead of during the entire shift,
- Improved maintenance procedures and schedules,
- Reduced drafts and air movements around the degreasers, and
- Trained operators on proper racking techniques and cycle times.

Westinghouse estimates that the improvements reduced air emissions by 60% and waste still bottoms by 70%. Other advantages include a reduction in SARA Title III toxic chemical emissions and an improved workplace environment.

The equipment modifications cost about $46,000. Annual cost savings total about $59,000 for a payback period of less than one year.

Dragout Reduction

Dragout reduction is a cost-effective method of minimizing wastes and raw material usage in electroplating/metal finishing dip tank operations. Dragout, the amount of solution carried over from tank to tank, increases wastewater treatment demands, causes loss of chemicals, and can cause cross-contamination of metal finishing baths. The amount of dragout per surface area of the part is influenced by part configuration, speed of withdrawal, dwell times above the tank, viscosity of the solution, and solution concentration.

Westinghouse has initiated dragout reduction schemes at two plants in Puerto Rico and North Carolina. The Puerto Rican facility operates metal finishing dip tanks equipped with manually-operated hoists to pretreat parts prior to spray painting. Dragout reduction techniques employed at the facility were:

- Racking parts to minimize horizontal surfaces and collection points,
- Shaking and/or tilting parts before transfer to the next tank,
- Increasing the dwell times above the tanks, and
- Changing the design of some parts to include small drain holes in solution collection points.

These techniques are expected to reduce dragout by 75%. Raw material savings of $11,000/year are expected in addition to savings on wastewater treatment plant sludge disposal.

The North Carolina facility uses dip tanks equipped with an automatic hoist system to perform barrel and rack plating on steel and copper parts. The techniques used to optimize raw material usage and minimize wastewater included:

- Upgrading the hoist control system to allow variable dwell times, decreased withdrawal rates, and rotation of barrels above tanks;
- Purchasing barrels with larger holes to facilitate draining and reduce cling;
- Increasing the use of rack plating, which causes much less dragout than barrel plating; and
- Improving the layout of the plati facilitate parts flow and reduce c tamination of baths.

By implementing these impr Westinghouse expects to reduce dr over 80% and significantly decre taminant loading to the wastewater t plant.

Minimizing Wastewater Treat Sludges

Two methods for minimizing wa treatment sludges have been util Westinghouse. The first method using sodium hydroxide (caustic s stead of calcium hydroxide (lime) t pH and precipitate metals during wa treatment. This decreases sludge ge 50% to 75%. Although sodium hydr usually more expensive than lime, will probably be realized due to sludge disposal costs.

Secondly, Westinghouse has i sludge dryers at several facilities to i the solids content of filter press sl 60% or more. At one facility, install a sludge dryer resulted in oper savings of over $20,000/year month payback on the $31,000 inves

Electrostatic Spray Paintin

In the last year, Westinghouse h graded many of its spray painting ope from conventional air-atomized spra low-solids paint to electrostatic spra high-solids paint. The following b have been experienced in these situat

- New paint requirements are redu 70%,
- Volume of solids generated from wash spray booths is reduced by 75
- Total volume of solvents emitted duced by 80%.

On a per gallon basis, high-solids usually cost twice as much as low- paints. However, cost savings may s realized because so much less high- paint is required. The costs asse upgrading to electrostatic paint capital cost of electrostatic spray equi

and operator retraining costs. Payback periods of about one year are typical.

Resin and Solvent Recovery from Laminate Production

Thermosetting laminates are produced at several Westinghouse facilities. The manufacturing process generates waste organic resins (e.g., resins with expired shelf-life, off-specification material, surplus due to overproduction, and leftover resin at the end of production runs). Spent solvents also result from equipment-cleaning activities.

A Westinghouse facility in Pennsylvania has installed a thin-film evaporator to distill and recover solvents from 75% of the waste resins and spent solvents generated at the plant. (Some resins cannot be treated in the thin-film evaporator because they are incompatible.) The recovered solvent (70% of the thin-film evaporator feed) is used to clean equipment. The evaporator bottoms are incinerated offsite. Implementation of the solvent recovery scheme has saved the company about $26,000/yr in operating costs. This represents raw material and disposal cost savings minus the energy and labor costs associated with the thin-film evaporator.

In addition to the thin-film evaporator, the facility has implemented the following minimization procedures:

- Resins leftover from production runs are drummed and reused whenever possible,
- Only resins with expired shelf-life are treated in the thin-film evaporator,
- Resin storage and supply procedures have been improved to avoid shelf-life expirations, and
- Production scheduling has been modified to minimize resin changeovers.

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Environmentally Smart Accounting: Using Total Cost Assessment To Advance Pollution Prevention

Allen L. White, Monica Becker, and Deborah E. Savage

Conventional project financial analysis often fails to capture the full range of costs and savings associated with pollution prevention (P2) investments. Thus, managers need to rethink their approach to cost inventory, cost allocation, time horizon, and profitability analysis to ensure that P2 investments are treated fairly in the capital budgeting process. This article shows how total cost assessment can often help level the playing field for P2 investments that might otherwise be tagged as uncompetitive and unprofitable.

DESPITE MOUNTING REGULATORY pressures and market incentives, industry has been slow to shift from end-of-pipe control strategies to more prevention-oriented practices.[1] If, as many argue, pollution prevention (P2) serves the interests of business by increasing efficiency and profits, what explains industry's continuing reluctance to move aggressively toward a preventative mode of environmental management? And why, in light of the much-heralded benefits of prevention strategies, are firms often surprised with the profitability potential of P2 projects in contrast to the "must-do," compliance-driven capital investments?

The explanation for these contradictions stems from at least two aspects of corporate environmental management. First, organizational structure and management behavior may impede pollution prevention projects from entering the firm's capital budgeting process from the outset, thereby precluding such projects from systematic consideration. Second, once a P2 project successfully enters the capital budgeting process and competes with other projects for limited capital resources, current methods of profitability analysis may discriminate against the P2 project.

Profitability analysis reflects how managers inventory and allocate costs, and what time horizons and financial indicators are selected to estimate the return on investment. This article examines the proposition that conventional methods of profitability analysis may systematically diminish the prospects of prevention-oriented investments in the highly competitive capital budgeting arena. This analysis is based on recent studies for the Environmental Protection Agency's (EPA) Pollution Prevention Division[2] and the New Jersey Department of Environmental Protection and Energy,[3] a recent update of these studies for the Organization for Economic Cooperation and Development (OECD),[4] and ongoing work with a number of firms that are exploring alternative methods of project profitability analysis.

*Dr. **White** and Dr. **Savage** are, respectively, director and research associate in the risk analysis group at the Tellus Institute in Boston, Massachusetts. **Monica Becker**, formerly with Tellus, is affiliated with the Center for Technology, Policy, and Industrial Development at the Massachusetts Institute of Technology.*

By lumping prevention projects into the "must-do" category, the typical tendency is to draw narrow boundaries around costs, savings, and revenues, dispense with in-depth analysis, and thereby omit or underestimate the potential returns from undertaking the investment.

Biases in Conventional Capital Budgeting

Conventional capital budgeting processes often fail to capture the full range of benefits from pollution prevention projects due to two distinct, but related, biases. The first bias arises from the tendency of firms to place prevention projects in the category of "profit-sustaining" or "must-do" compliance investments. This stands in contrast to "profit-adding" (including cost reduction) projects and market-expansion projects that are invariably the higher management priorities in terms of corporate growth and market development. By lumping prevention projects into the "must-do" category, the typical tendency is to draw narrow boundaries around costs, savings, and revenues, dispense with in-depth analysis, and thereby omit or underestimate the potential returns from undertaking the investment.

The second bias in conventional budgeting processes is inherent in the nature of prevention investments. Because prevention, by definition, implies upstream changes in material inputs and choices of process technologies, such investments tend to trigger multiple, and often indirect or second-order midstream and downstream effects in the production process. These may take the form of reduced compliance, insurance, and waste management costs, reduced worker absenteeism, as well as avoidance of contingency costs linked to acute events caused by a sudden release of hazardous materials. Furthermore, prevention measures increasingly are tied to less tangible and difficult-to-quantify benefits such as corporate and product image, and gaining a foothold in the marketplace for green products. To the extent that prevention investments create such advantages, they tend to occur over periods longer than the two to five years often used in conventional project financial analysis. They also require the firm to identify and allocate costs at a level of detail that goes beyond what is typically practiced in capital budget analyses.

The Building Blocks of Total Cost Assessment

Profitability analysis of a capital investment in pollution prevention contains four elements: (1) cost inventory, (2) cost allocation, (3) time horizon for profitability analysis, and (4) profitability indicators. Total Cost Assessment (TCA) is an approach to these elements that accounts for the particular characteristics of P2 projects.

Cost inventory

Identifying all costs and savings associated with a pollution prevention investment is the first element of TCA. As with any industrial investment, such costs may be classified as one-time capital costs incurred at the outset of the project, or as recurrent (normally annual) operating costs that are incurred repeatedly over the life of the project. Unlike most investments, however, environmental projects are associated with certain costs, savings, and revenues that are relatively uncertain in character (what are they?), magnitude (how large will they be?), and timing (at what point in the

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project life cycle will they occur?).

This uncertainty results from two conditions: (1) the complexity of assessing risks associated with the use and transport of, and possible exposure to, hazardous substances; and (2) changing regulatory and judicial decisions that result in upward and downward shifts in project costs. Some costs are straightforward, although they are not necessarily routinely identified by managers. Such costs may include monitoring, training, and preparing manifest forms for the off-site shipment of hazardous waste. Others, however, fall into the category of contingent costs—those that may materialize if certain events occur. These could be exceeding a permitted emissions limit, an off-site spill during transport of waste, a leak in a lined and permitted hazardous waste landfill, disposal of wastes at an unpermitted site, or an acute event leading to an environmental release in an abutting neighborhood. All of these are events are probabilistic in nature, that is, they may occur, but we hope they won't. If they do, certain costs will be borne by the firm.

Whereas conventional project financial analysis generally includes only the most obvious, direct, and tangible capital and operating items, TCA expands the inventory to encompass a broader range of costs, savings, and revenues. Selected examples from each of these categories are shown in **Table 1**.

It is essential to recognize that although an expanded cost inventory is an essential ingredient in rigorous profitability analysis, it does not incorporate the social costs of a proposed project.

It is essential to recognize that although an expanded cost inventory is an essential ingredient in rigorous profitability analysis, it does *not* incorporate the social costs of a proposed project. **Figure** 1 illustrates these key differences. Costs conventionally covered in a project financial evaluation are shown inside the first rectangle. These costs are a subset of, or are nested within, a second rectangle that includes many of the indirect costs, liabilities, and less tangible items listed in Table 1. By our definition, this is what would appear in a project analyzed using the TCA approach.

An even broader approach than TCA is a larger inventory covering social costs resulting, for example, from health and ecological damages related to unregulated air toxics, wetlands loss, or unsustainable forest use. These externalities, which are no less real than TCA costs, are still conceptually distinct, because they have no financial consequences for the firm under current legal and regulatory conditions. Although the trend in environmental regulation suggests there may be a gradual convergence of the inner two rectangles with the outer rectangle, TCA should not be construed as a social accounting methodology.

Cost allocation

Cost allocation procedures define how production costs are assigned to specific product or process lines, or to overhead accounts. Allocation in medium and large firms is typically the responsibility of financial and production staff. They aim to properly debit and credit production processes/units on an activity basis, thereby providing the foundation for pricing according to real costs, a practice commonly

Table 1. Total Cost Assessment: Examples of Costs and Benefits

Direct Costs

- Capital expenditures
  - –buildings
  - –equipment
  - –utility connections
  - –equipment installation
  - –project engineering
- Operation and maintenance expenses/revenues
  - –raw materials
  - –labor
  - –waste disposal
  - –utilities: energy, water, sewerage
  - –revenue from recovered material

Indirect or Hidden Costs

- Compliance costs
  - –permitting
  - –reporting
  - –tracking
  - –monitoring
  - –manifesting
  - –training
  - –waste handling
  - –recordkeeping
  - –labeling
  - –testing
  - –emergency preparedness
  - –medical surveillance
- Waste storage
- Operation of on-site pollution control equipment
- Raw materials costs linked to nonproduct output (NPO)
- Environmental insurance (acute events, gradual impairment)

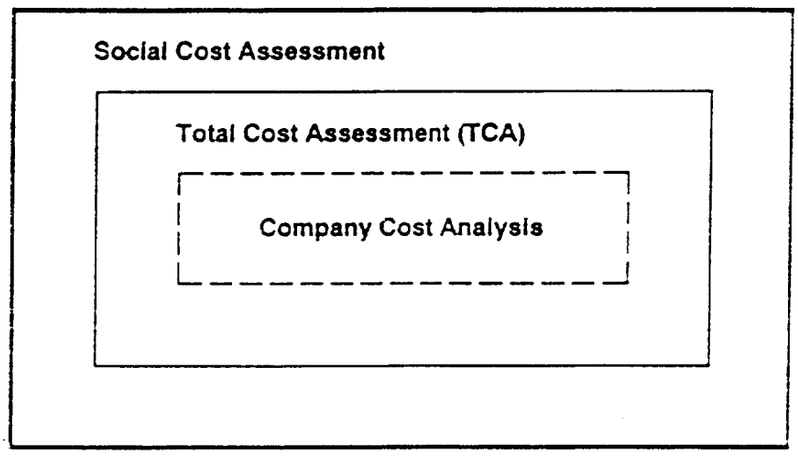
Liability Costs

- Penalties and fines
- Personal injury and property damage

Less Tangible Benefits

- Increased revenue from enhanced product quality
- Increased revenue from increased share of green product markets
- Reduced worker compensation and absenteeism costs from improved employee health
- Increased productivity from improved employee relations
- Reduced staff burdens in dealing with community concerns

Figure 1. Project Investment Cost Boundaries



known as full-cost accounting. Proper allocation is indispensable to sound investment profitability analysis. When costs are improperly allocated either by lumping them into overhead accounts and/or by assigning them incorrectly to production processes, profitability analyses cannot proceed on a rationale basis.

Two methods of cost allocation are commonly practiced. One relies on a materials balance approach, using standard unit, batch, lot, product input requirements or recipes. The other is materials accounting, based on inventory data of material inputs at the beginning and termination of a reporting period, or on measurement (e.g., volume or weight) of waste materials from production lines. In some instances, the two methods may be used in tandem to reconcile discrepancies between materials balance estimates (with batch model data) and materials accounting data (which rely on physical measurement). Such discrepancies invariably arise because of measurement/instrumentation shortcomings, excursions from standard recipes, and exclusion of certain steps in the production process that consume material inputs (e.g., cleaning during and between production campaigns or testing prior to introduction of new products).

For purposes of investment analysis, the ideal cost allocation system has two principal attributes. First, the system should allocate all costs to the processes responsible for their creation. This is a perennial challenge to financial officers and cost accountants who oversee the assignment of costs into either overhead or, alternatively, product or process accounts. Waste disposal costs, for example, are often placed in overhead accounts. A more rigorous approach would assign such costs to a discrete operating unit or process in the firm's production system.

Second, costs should be allocated in a manner that is reflective of the way that costs are actually incurred. Some firms, for example, allocate waste disposal costs across operating centers—administrative, research and development, and manufacturing—on the basis of floor space, rather than on the quantity and type of waste generated by each. This hampers a rigorous estimation of the financial benefits of reduced waste generation by uncoupling points of generation from points of reduction. Careful allocation, requires commitment, time, and financial resources, especially in large and complex production activities. Nonetheless, it is integral to identifying the sources of waste generation and the benefits of changing current practices to more preventative management.

Time horizon

Time horizons of five years or more enable the financial analysis to capture costs, savings, and revenues that occur well after the initial investment. This extends beyond the two-to-five year time frame used by many firms to evaluate investment profitability. A longer time horizon, preferably ten to fifteen years, is particularly critical to capture out-year liability, recurrent savings due to waste avoidance, and revenue growth linked to market development of environmentally friendly products. Without a longer horizon, the financial analysis runs the risk of failing to capture the very benefits for which the pollution prevention investment was originally targeted. Of course, the readiness of firms to extend their investment analysis to this longer horizon depends on numerous considerations, including size, capital availability, and competition from alternative investments of the same or higher priority. Notwithstanding these limitations, a longer time horizon should be applied at minimum to compare near and longer-term returns to a potential pollution prevention investment.

A longer time horizon, preferably ten to fifteen years, is particularly critical to capture out-year liability, recurrent savings due to waste avoidance, and revenue growth linked to market development of environmentally friendly products.

Financial indicators

Financial indicators for pollution prevention projects should meet two criteria: (1) a capacity to incorporate all cash flows (positive and negative) over the life of the project; and (2) a capacity to integrate the time value of money through appropriate discounting of future cash flows. Indicators that meet these criteria are best equipped to capture the broadest range of costs, savings, and revenues, many of which may occur years after the initial investment. Net Present Value, Internal Rate of Return, and the Profitability Index are examples of such indicators; payback is not. A brief description of each shows why.

Under the *Net Present Value (NPV)* method, the present value of each cash flow, both inflows and outflows, is calculated and discounted at the project's cost of capital. The sum of the discounted cash flows is the project's NPV. A positive NPV means a project is worth pursuing; a negative NPV indicates it should be rejected. If the availability of capital is constrained (as it usually is), or if several projects are competing with one another, other things being equal, the

project or combination of projects with the highest positive NPV should be chosen. The NPV method, particularly as applied to long-term projects with significant cash flows in later years, is very sensitive to the level of the discount rate. Thus, for a project with most of its cash flows in the early years, its NPV will not be lowered much by increasing the discount rate. On the other hand, the NPV of a project with cash flows that come later will be substantially lowered for an increased discount rate, rendering the project a much less attractive investment opportunity.

The *Internal Rate of Return (IRR)* method calculates the discount rate that equates the present value of a project's expected cash inflows to the present value of the project's expected costs. Thus, the basic formula to calculate the IRR is the same as that for the NPV; for the IRR, the NPV is set to zero and the discount rate is calculated; for the NPV, the discount rate is known and the NPV is calculated. A project is worth pursuing when the calculated IRR is greater than the cost of capital to finance the project. When several projects are vying for limited resources, all else being equal, the project with the highest IRR should be pursued.

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The *Profitability Index (PI)* is simply the present value of benefits (cash inflows) divided by the present value of costs (cash outflows). It shows the relative profitability of a project, or present value benefits per dollar of costs. Projects with profitability indices greater than 1.0 should be pursued, and the higher the PI, the more attractive the project.

Payback is the simplest and most common of the indicators for evaluating investment profitability. It provides a quick, back-of-the-envelope appraisal of the financial prospects of a project. Although the payback calculation may suffice for a preliminary assessment, it should not be relied upon as the sole method for project evaluation. The payback period is the expected number of years required to recover the original project investment; it can be calculated before or after taxes, and serves as a type of break-even calculation. If cash flows materialize at the expected rate until the payback year, then the project will break even. The regular payback, however, does not account for the cost of capital, so that the cost of the debt and equity used in the investment is not reflected in the cash flows or the calculation. Another major drawback of the payback method is that it does not take into account cash flows beyond the payback year. The payback period does, however, provide an estimate of how long funds will be tied up in a project. Thus, it is often used as an indicator of project liquidity.

TCA in Practice

To assess how TCA works in practice, we offer the following example of a TCA project analysis from one of several firms that collaborated with the Tellus Institute in its TCA studies. The company's manufacturing facility is a specialty paper mill that produces a

variety of uncoated and on-machine and off-machine coated papers, as well as carbonizing, book, and release base papers. The coating used is a latex (i.e., nonsolvent) formulation containing clay, styrene butadiene, starch, and polymers. This example was chosen because it is a particularly powerful illustration of the value of a TCA approach. Other cases may demonstrate more or less dramatic results for reasons discussed below.

Background on the manufacturing process

Paper machine white water, a mixture of water and residual fiber and filler (clay and calcium carbonate) that drains out of a sheet of paper as it travels across the paper machine, is usually captured by a white water collection system dedicated to one paper machine. Typically, some or all white water is recycled back into the papermaking system to recapture water, fiber, and filler. As a pollution prevention measure to reduce water use and wastewater treatment, white water may be passed through a save-all screening device to separate fiber and filler from water; fiber, filler, and water are then recycled back into the system. The save-all produces a clear stream of water that can be used in numerous paper machine operations.

In this mill, two paper machines, sharing a common white water system, produce a variety of paper grades made with either acid-, neutral-, or alkaline-sizing chemistry.[5] Machine 1 has a save-all system that filters fiber and filler prior to discharging into the joint white water system. This material is recycled back into the papermaking system. When the machines are using different sizing chemistry (e.g., when Machine 1 is producing acid-sized paper and Machine 2 is producing alkaline-sized paper), the mixed white water from both machines is not reusable and must be sewered. Under these conditions, a large flow of potentially reusable water from both machines, and fiber and filler from Machine 2, is lost to the sewer.

Prompted primarily by the lack of spare water effluent pumping capacity and a desire to better understand the rather complex, old white water piping system, the mill commissioned a study titled "White Water Recycle Feasibility Study" in 1988. The study, completed in August of 1989, had several objectives: ". . . to review the design and operation of the mill and recommend changes that would help reduce peak effluent flows, reduce BOD [biological oxygen demand] in the effluent and reduce total fresh water intake on a millwide scale." The resulting report contained detailed engineering drawings of the fresh water, white water, and paper machine systems and two recommendations for process modifications.

The first recommendation . . .in the feasibility study was the installation of a second save-all to handle the white water from Machine 2.

Pollution prevention project description

The first recommendation (called Phase I) in the feasibility study was the installation of a second save-all to handle the white water from Machine 2. Because the white water systems under this scenario would remain separate for Machines 1 and 2, this phase would allow

recovery of fiber from white water, but only permit recovery of clarified white water if the grades being produced on the machines were compatible. Otherwise, the water would have to be sewered.

Under Phase II, the white water systems would be split, so that each machine would have a dedicated system. In combination with Phase I, Phase II would permit fiber, filler, and water reuse on both machines at all times. This phase would require installation of a new save-all, a new pump, piping, and controls. Available pulping and stock storage capacity could be used to pulp separately for each machine.

At the request of the mill, we focused our analysis on the combined Phases I and II. This option was most interesting to the mill because it maximizes recovery of water, fiber, and filler and reduction of BOD and solids in wastewater.

The company analysis consists of the 1989 capital estimate (adjusted for inflation and escalated by 12.5 percent) and only those operating costs and savings that the company typically includes in project financial analyses . . .

Company financial analysis versus TCA

The company analysis consists of the 1989 capital estimate (adjusted for inflation and escalated by 12.5 percent) and only those operating costs and savings that the company typically includes in project financial analyses for projects of this type, which are

- Raw material—fiber and filler;
- Energy and chemical use for new equipment;
- Wastewater treatment fees; and
- Changes in labor costs.

The TCA contains these and other operating costs and savings that were developed in the course of this study. On the savings side, the TCA includes the following:

- An average reduction in fiber and filler loss of 1,200 tons a year for an annual savings of $421,530;
- A reduction in fresh water usage of 1 million gallons a day and a commensurate reduction in cost for fresh water treatment and pumping, for a savings of approximately $112,420 a year;
- A reduction in energy use for fresh water heating amounting to a savings of approximately $393,400; and
- A reduction in wastewater generation of approximately 1 million gallons a day for a savings of approximately $54,750 a year in wastewater pumping and $68,240 a year in wastewater treatment fees.

Annual operating costs are expected to increase in the following areas:

- Chemical flocculating agents used in the save-all to promote solids/water separation will cost approximately $28,700 a year;
- Electric costs for new equipment operation will increase operating costs by approximately $107,280 a year; and

Table 2. Overview of Cost Inclusion by Company and TCA for Whitewater/Fiber Recycle Project

Costs	*Company*	*TCA*
Capital Costs		
Purchased equipment	X	X
Materials (e.g. piping, elec.)	X	X
Utility systems	X	X
Site preparation	X	X
Installation	X	X
Engineering/contractor	X	X
Start-up/training		
Contingency	X	X
Permitting		
Initial chemicals		
Working capital		
Salvage value		
Operating Costs		
Direct Costs[a]		
Raw materials/supplies	P	X
Waste disposal		
Labor	X	X
Revenues—general		
Revenues—by-products		
Other:		
transportation		
Indirect Costs[b]		
Waste management:		
hauling		
storage		
handling		
waste-end fees/taxes		
hauling insurance		
Utilities:		
energy	P	X
water		X
sewerage (POTW)	X	X
Pollution control/solvent recovery		
Regulatory compliance		
Insurance		
Future liability		

X = Cost(s) Included P = Cost(s) Partially Included

[a] We use the term "direct costs" here to mean costs that are typically allocated to a product or process line (i.e., not charged to an overhead account) *and* are typically included in project financial analysis.

[b] We use the term "indirect costs" here to mean costs that are typically charged to an overhead account *and* typically not included in project financial analysis.

- An increase in labor cost of approximately $3,120 a year is expected for operation of new equipment.

Table 2 presents a comparison of the company versus TCA cost inventory. The company entries reflect those normally included by the firm in a project justification analysis. The *"P"* in Table 2 indicates costs that are partially included in conventional analysis. The TCA column incorporates a more expansive inventory based on discussions with the firm regarding cost items that rightfully belong in the analysis, but are normally omitted. To ensure comfort on the part of the collaborating company, only the most obvious and significant omissions were highlighted. This led to results that most likely err on the conservative side (lesser TCA effect) than a more expansive analysis incorporating, for example, regulatory compliance costs, might show.

In this white water/fiber reuse project, a number of cost items appear in the TCA column that are either partially or entirely omitted from the company analysis. These include savings in raw materials costs from recovery of fiber and filler; a savings in fresh water usage and costs, as well as associated fresh water treatment and pumping; a savings in energy use for fresh water heating; and a savings in wastewater pumping and treatment fees.

The dramatic difference in the analyses of the profitability for this project using the company and TCA methods can be traced to the partial and total omission of several key reductions in direct and indirect costs.

The dramatic difference in the analyses of the profitability for this project using the company and TCA methods can be traced to the partial and total omission of several key reductions in direct and indirect costs. **Table 3** shows the financial impact of these omitted savings by comparing the company and TCA profitability analyses. A project costing $1.47 million using the company analysis yields an annual savings of $350,670 versus $911,240 in the TCA analysis. NPV over a fifteen-year time horizon jumps from $360,301 to $2.8 million. The IRR over fifteen years increases from 21 percent to 48 percent. At the same time, the payback period declines from 4.2 to 1.6 years.

Neither the existing nor alternative technology generates Resource Conservation and Recovery Act (RCRA) wastes. Thus, the project does not affect wastestreams that require on-site management or disposal, nor does it affect any regulatory compliance activities at the site; therefore, the financial analysis does not include costs for these activities. Thus, unlike projects that potentially reduce or eliminate the use of hazardous materials, this project produces no significant regulatory compliance savings. In addition, no impacts on revenue are expected, because neither product quality nor production rates will be improved. A project of this nature is also unlikely to affect product or company image in a way that reduction or elimination of a major air toxic (e.g., volatile organic compound emissions from solvent-based coating processes) might achieve. Finally, no tangible impact on avoided future liability is expected for this project.

In sum, the TCA/company differential in profitability occurs in a pollution prevention project involving a relatively straightforward.

Table 3. Summary of Financial Data for White Water and Fiber Reuse Project

Costs and Savings	*Company Analysis*	*TCA*
Total Capital Costs	$1,469,404	$1,469,404
Annual Savings (BIT)[a]	$ 350,670	$ 911,240
Financial Indicators		
Net present value—years 1-10	$ 47,696	$2,073,607
Net present value—years 1-15	$ 360,301	$2,851,834
Internal rate of return—years 1-10	17 %	46 %
Internal rate of return—years 1-15	21 %	48 %
Simple payback (years)	4.2	1.6

[a] Annual operating cash flow before interest and taxes.

proven technology without inclusion of some of the more indirect, less tangible financial benefits that may well occur with more complex and hazardous production technologies.

Looking Ahead

Aside from the specifics of our white water/fiber reuse example, how TCA affects profitability depends on several conditions:

- The degree to which hazardous materials management and liability costs are part of each process;
- The extent to which savings actually materialize through, for example, reallocation of unneeded labor from waste management functions to new, productive activities;
- The extent to which company practices already have moved in the direction of TCA;
- The degree to which a proposed project yields a marketable green product or company image; and
- The degree to which alternative technologies generate new costs that may neutralize, or even exceed, cost savings associated with shifting away from an existing process.

A priori, TCA does not ensure profitability for a pollution prevention project. Depending on project specifics, projects can range from dramatically positive results (as shown above), to those with positive but modest advantages, to those in which NPV and IRR actually diminish when applying a TCA approach. Of course, even in the latter case, diminished profitability is not synonymous with social undesirability. In other words, it is entirely possible that a pollution prevention project may yield net positive benefits to society as whole,

but still fail to meet the internal hurdle rate of the firm that is necessary to gain management approval. When this is the case, government corrective intervention in the form of market-based incentives, voluntary programs, or mandates is appropriate to induce modification of corporate investment behavior.

Though outcomes vary, one can be sure that TCA is in the self-interest of the firm. It rationalizes management decision making by leveling the playing field for all projects that enter the capital budgeting process.

Though outcomes vary, one can be sure that TCA is in the self-interest of the firm. It rationalizes management decision making by leveling the playing field for all projects that enter the capital budgeting process. This is particularly true for upstream projects involving process redesign, product reformulation, and materials substitution, that is, the core of pollution prevention strategies. These kinds of projects typically are rife with indirect, hidden, and intangible costs and savings that TCA is particularly adept at identifying.

In the long term, TCA can serve as a substantial force in recasting the must-do and inherent loser image of environmental projects into a more positive profit-adding and market-expanding image. TCA also serves to rationalize a firm's capital budgeting practices, helps to quantify and make transparent all project costs, and catalyzes new ways of thinking about pollution reduction. Effective application of TCA typically requires the involvement of multiple staff—financial, environmental, operations, purchasing, marketing, R&D—which promotes more integrated and innovative environmental strategies in the firm.

For these reasons, what firms may see as the high initial cost of gearing up for TCA is better viewed as an up front fixed cost to revamp accounting systems to become more environmentally-conscious. When viewed from this perspective, TCA yields recurrent benefits that may be amortized over many budgeting cycles and during the transition to more preventative management strategies. ◆

Notes

1. Hoffman, A., "Teaching Old Dogs New Tricks: How To Create Incentives for Industry To Adopt Pollution Prevention," *Pollution Prevention Review*, Winter 1993-94, pp. 1-11.

2. White, A. M. Becker, and J. Goldstein, "Total Cost Assessment: Accelerating Industrial Pollution Prevention Through Innovative Project Financial Analysis, With Applications to the Pulp and Paper Industry," prepared by Tellus Institute for U.S. EPA, Office of Pollution Prevention, December 1991.

3. White, A.M. Becker and J. Goldstein, "Alternative Approaches to the Financial Evaluation of Industrial Pollution Prevention Investments," prepared by Tellus Institute for the New Jersey Department of Environmental Protection, Division of Science and Research, November 1991.

4. White, A., "Accelerating Corporate Investment in Clean Technologies Through Enhanced Managerial Accounting Systems," Draft Background Paper, prepared by Tellus Institute for the Organization for Economic Co-Operation and Development, Programme on Technology and Environment, January 1993.

5. Sizing is added to pulp to reduce water absorbency in the final paper. The pH (i.e., acidity or alkalinity) of the pulp must be adjusted according to the type of paper desired and sizing used.

Life-Cycle Costing and Pollution Prevention

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Paul E. Bailey

Life-cycle costing has been widely touted as an aid for exploring pollution prevention alternatives—paper or plastic bags, disposable or reusable diapers, glass or plastic containers. This article explains life-cycle costing, its historical applications, its potential applicability to pollution prevention, and some of its limitations. Examples are given of recent applications of life-cycle costing to environmental issues.

THE CONCEPT OF pollution prevention has much popular support, yet how to make it happen is often unclear. Alternative products and services are difficult to rate in terms of environmental "greenness," whatever that may mean. Which is better: plastic or paper bags? Disposable or reusable diapers? Electric or gasoline-powered vehicles? Without some rating scale, how can we choose?

Life-cycle costing is receiving attention as the kind of comprehensive "cradle-to-grave" decision aid that could foster greater strides in pollution prevention. The goal of this paper is to explain life-cycle costing and explore its applicability to environmental issues and pollution prevention. The paper presents the history and applications of life-cycle costing in nonmathematical terms. The limits of classic life-cycle costing are identified and contrasted with both "risk assessment" and "full cost accounting," two other approaches for environmental decision making. The paper concludes with an overview of some recent applications of these tools and suggested directions for the future.

Life-Cycle Costing

Twenty-five years ago in April 1965, the Logistics Management Institute in Washington, D.C., prepared a report for the Assistant Secretary of Defense for Installations and Logistics entitled "Life Cycle Costing in Equipment Purchase" that led to a revolution in guidelines for procurement of major defense systems and equipment. Spawned by the arrival of the "whiz kids" in Washington, life-cycle costing used the mathematical tools being taught in the nation's advanced business schools, recognizing that operation and maintenance (O&M) costs were substantial components of the total costs of owning equipment and systems.

In fact, "ownership costs" can far exceed procurement costs. As the government procurement process is oriented toward securing the best value from competing bidders, life-cycle costing was intended to

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facilitate more intelligent choices. A device with relatively low purchase costs but high operations costs (e.g., energy-inefficient) and/or high maintenance costs (e.g., not very reliable) may not in fact be a better value. By considering the full costs over the life cycle of the system and the time value of money (e.g., discounting), better comparisons can be made. In addition, developing an overall quantitative picture of the life-cycle costs of an item increases the attention paid to operation and maintenance costs with the potential for improved design that reduces such costs.

Several trends combined to increase the costs of O&M through the '70s and '80s, including rising labor costs and decreased reliability due to increased system complexity, general price and wage inflation, and steep increases in energy costs. Thus, as the relative importance of ownership costs has increased compared to purchase costs, interest in life-cycle costing has grown. A recent bibliography has identified more than a thousand references on life-cycle costing.[1]

Energy requirements of systems, equipment, and buildings are particularly amenable to life-cycle costing as these requirements are relatively easy to predict and easy to monetize.

Energy requirements of systems, equipment, and buildings are particularly amenable to life-cycle costing as these requirements are relatively easy to predict and easy to monetize. Both alternative product/system specifications and energy conservation actions (e.g., special lighting, insulation) are amenable to an analysis that calculates payback and return on investment. Recognizing this, Congress enacted the National Energy Conservation Policy Act in 1978, which requires that every new federal building be life-cycle cost-effective. Many states also enacted legislation making life-cycle cost analysis mandatory in the planning, design, and construction of state buildings.

Applications for life-cycle costing

Typical life-cycle cost analysis applications include:

- Aircraft
- Computers
- Military systems
- Heavy industrial equipment, tractors
- Automobiles and tires
- Ships
- Appliances (e.g., lighting, cooling, heating)
- Hospital facilities and medical equipment
- Buildings
- Office equipment
- Energy systems

All of these items are well suited to life-cycle cost analysis. Notably, for each, the government or corporate purchaser can define well-specified performance characteristics—speed, acceleration, capacity, accuracy, efficiency, and so on. Competing products and systems that satisfy the required performance criteria can then be evaluated and compared in terms of life-cycle costs. Low-tech, small-

scale items such as bags, diapers, and packing material have not traditionally been the subject of life-cycle cost analysis.

In comparing competing trucks, for example, that have equivalent carrying capacity in volume and tonnage, a life-cycle cost analysis would consider:

- Expected lifetime of use carrying equivalent loads; the longer lasting vehicle would have an edge
- Fuel efficiency over the life of the truck; the vehicle getting more miles per gallon would look attractive
- Maintenance costs over the life of the truck; the vehicle designed for ease of maintenance (e.g., hours of mechanic time plus materials) would appear superior
- Reliability and repair costs over the life of the truck; both expected frequency and nature of breakdowns and costs of repairs would be important

By reducing these elements to comparable dollar terms, the buyer can assess potential tradeoffs: the lighter weight vehicle may get more miles per gallon but have a shorter expected lifetime; a vehicle may have lower maintenance costs but be less reliable. Life-cycle costing permits easy analysis of such variables by translating them into the common units of today's dollars.

Key factors and limitations

Life-cycle cost analysis requires thinking through and identifying all the cost-bearing activities associated with the item or system throughout its lifetime, from acquisition through disposal.

Life-cycle cost analysis requires thinking through and identifying all the *cost-bearing activities* associated with the item or system throughout its lifetime, from acquisition through disposal. Each activity must then be "costed" in the nominal dollars of the year(s) the costs are expected to arise. Existing cost data must be collected or created and, for some activities, projected into the future. Once the costs are developed, the analyst can "discount" them to presentday dollars to facilitate comparisons with competing goods and systems. There is likely to be a significant element of uncertainty in the cost estimates for many applications of life-cycle costing; the analyst must accept this as unavoidable, while striving to do the best possible job.

This paper will not go into the many mathematical formulas that can be used in life-cycle costing. But it is important to note the key variables:

- Procurement cost
- Delivery and installation costs
- Annual operating costs including the costs of energy, supplies, labor, materials, and insurance
- Annual maintenance cost
- Taxes
- Salvage value or disposal cost

- Life cycle in years
- Discount and escalation (anticipated inflation) rates

Anyone familiar with capital investment evaluation methodology will recognize all these factors as the costs businesspeople consider in light of projected returns on a potential investment. (One difference between private and public sectors lies in the discount rate that ought to be used, a subtlety we need not address here.) Capital investment decisions resemble procurement decisions in many respects, particularly when there are several projects competing for capital funds. However, capital investment methodology also applies to an individual project using objective criteria such as return on investment, payback period, and cost of capital as evaluative benchmarks, whereas life-cycle costing is usually thought of in the context of competing expenditures, given a need or desire to buy.

Life-cycle costing should also be distinguished from "value engineering," although there are some overlaps. Life-cycle costing can set the stage for value engineering, which aims to identify potential cost-sharing efficiencies from changes in the design, manufacture, or use of goods or systems. The purpose of life-cycle costing is to measure or describe costs, not to minimize them. However, to minimize costs, one has to know what the costs are—which life-cycle costing can provide.

The purpose of life-cycle costing is to measure or describe costs, not to minimize them. However, to minimize costs, one has to know what the costs are—which life cycle costing can provide.

Inherent in life-cycle costing are some subtle limiting assumptions. Key is the ability to identify all the potential costs and monetize them; costs that are omitted will skew the analysis. Also, life-cycle costing cannot be used to compare apples and oranges; that is, it is a tool for distinguishing among *comparable items* that meet basic performance requirements. Life-cycle costing is not appropriate for choosing among products or systems with different goals, say tanks versus helicopters, or paper bags versus diapers. And, whereas governments and businesses in their buying decisions may not care much about aesthetics or other subjective aspects of comparable goods, retail consumers may find such factors compelling regardless of comparative cost (for example, natural versus synthetic fibers). The applicability of life-cycle costing to consumer behavior at the retail level needs more thought. In fact, when product "quality" is involved, purely economic criteria may not be controlling. In addition, life-cycle costing focuses on the procurement and ownership costs expected to be incurred by the purchaser; so-called social costs or externalized costs are not covered. This is a very serious limitation that will be further discussed below.

Pollution Prevention and Life-Cycle Costing

The hope for life-cycle costing is that it can enable us to make the difficult choices to achieve pollution prevention. Pollution prevention is the reduction in toxicity and/or volume of pollutants released to the environment and includes:

- Waste reduction at the point of generation
- Recycling and reclamation of waste materials
- Materials substitution or process changes

In the realm of pollution prevention, less is usually and clearly more; that is, less waste means more pollution prevention. And recycling and reclamation seem clearly better than disposal of pollutants in the environment. But *substitutions* are much more difficult to evaluate. PCBs were originally hailed for use in transformers as substitutes for materials of less stability. Asbestos likewise appeared to be a fiber of miraculous properties. Advances in medical science for a variety of conditions brought some new forms of radiation treatment that are now recognized as worse than the disease itself. Currently, advocates of pollution prevention encourage the substitution of water-based cleaners (or pigments) for solvent-based ones; but many aqueous cleaners can have adverse impacts on wastewater treatment plants and water bodies due to high BOD (biological oxygen demand) and metals. Can life-cycle costing help in fostering pollution prevention and avoiding perverse outcomes?

Life-cycle costing can help in pollution prevention decisions relating to products by ensuring that any O&M and disposal costs relating to pollution are considered in the analysis.

Life-cycle costing can help in pollution prevention decisions relating to products by ensuring that any O&M and disposal costs relating to pollution are considered in the analysis.

In the paper versus plastic bag question, many of the classic life-cycle costing elements such as maintenance and repairs are not applicable due to the short shelf-life and technical simplicity of the articles. Here, assuming equivalent performance (e.g., carrying capacity) of the bags, a supermarket chain or government procurement officer might consider the cost differential resulting from the greater bulkiness of paper bags—more storage space needed or more frequent refilling of storage bins. And, if paper bag storage areas attract insects, costs of pesticide application or monitoring of infestation would arise; and so on.

In deciding between stocking disposable or washable diapers (for example, in military hospitals or child care centers), a procuring agency such as the Department of Defense (DOD) would need to consider the costs of collecting and cleaning washable diapers, wastewater treatment and/or disposal, and the diapers' useful lifetime (and ultimate disposal) versus the costs of using and disposing of nonreusable diapers for an equivalent population of children.

By adding in the appropriate missing costs to the life-cycle costing approach described earlier, we can achieve the "full-cost accounting" that is likely to be necessary for evaluating pollution prevention projects. Such an expanded accounting forms the core of the Environmental Protection Agency's (EPA) *Pollution Prevention Benefits Manual*.[3] The *Manual* helps the user identify the costs involved in hazardous materials and hazardous waste management and describes how to estimate the net present value, internal rate of return, and annualized cost savings of pollution prevention projects.

The *Manual* distinguishes among four levels of costs:

- Usual Costs (Tier 0)—Equipment, materials, labor, etc.
- Hidden Costs (Tier 1)—Monitoring, paperwork, permit requirements, etc.
- Liability Costs (Tier 2)—Future liabilities, penalties, fines
- Less Tangible Costs (Tier 3)—Corporate image, community relations, consumer response, etc.

The *Manual* includes worksheets and data to assist in cost estimation. The *Manual* also presents an illustration applying the methodology to a hypothetical firm that is an electroplater of gold jewelry. Currently, the firm uses 1,1,1-trichloroethane (TCA) in a precleaning step that generates spent solvents; the firm could avoid generating such hazardous waste by replacing the TCA precleaner with a mechanized aqueous cleaner. Unless liability costs and less tangible benefits are considered, the economic justification for the change is not strong enough.

Some major corporations, including General Electric, Dow, and General Motors, take liability exposures so seriously that many now forbid off-site disposal except at approved facilities.

Existing references on life-cycle costing and related research described in this article have yet to factor in these important considerations. Notably, some major corporations, including General Electric, Dow, and General Motors, take liability exposures so seriously that many now forbid off-site disposal except at approved facilities. GE has even developed its own costing model including liability exposure.

In general, waste management costs for materials would be subsumed under annual operating and maintenance costs and final disposal costs, so long as there are costs involved. Solid waste and much liquid waste generate waste management costs depending on how they are handled, but disposal of some liquid waste and certain types of air emissions may be relatively costless to industry. For example, waste oil from truck maintenance may carry some management cost (so long as it is not dumped down the drain), but the emissions from exhaust trigger no costs to the truck owner. Bags impose no waste management costs on supermarket owners because their customers cart the bags away, but preventing or treating insect infestation of bag storage areas will impose costs. The DOD will likely incur solid waste management and wastewater treatment costs due to diaper use at their bases, although on-site disposal of diapers, for example, may be considerably cheaper than off-site disposal where the DOD has had the use of land for free. This raises a related point. The costs to the user of the good or system of its solid waste and air and water emissions may not fully reflect their cost to society. Economists have invented a term for such real costs to society that do not belong to anyone—they are "externalized" or "external costs."

External costs

So long as the prices of goods and services do not reflect their full costs to society (e.g., costs of pollution, environmental degradation),

the free market will operate to encourage relatively greater use of these goods and services and more resulting pollution. Due to externalities, "classic" life-cycle costing will not capture the full costs of pollution in its calculations. For organizations acting to minimize the costs of doing business, externalities are not their concern; but public agencies acting to improve public health and welfare and environmental quality need to incorporate the externalities into their decision making.

What are these externalities and can life-cycle costing be adapted to incorporate them? Cost externalities can include:

1. Potential legal liabilities; for example, for cleanup, damage to natural resources, damage to persons or property, and
2. Other costs incurred by society; for example, the costs of managing solid waste incurred by public agencies and other social costs not covered in (1) above because the legal system cannot or does not render them recoverable liabilities.

The state of the art is young, but the incorporation of externalities into life-cycle costing is feasible by building on past and ongoing work to monetize these externalities.

Liability costs. Development of methodologies for monetizing the potential liabilities associated with waste disposal was spurred by the enactment of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) of 1980, which created the Post-Closure Liability Trust Fund (PCLTF) and required EPA to assess the adequacy of the Congressionally established waste end tax to finance expected demands on the PCLTF. EPA contracted with ICF Incorporated to develop a sophisticated "Monte Carlo model" to estimate in dollar terms the liabilities that would be channeled to the PCLTF.[5] The results of this pioneering analysis were used by EPA in its Report to Congress on the PCLTF. The PCLTF was later abolished by Congress due to policy and political reasons as well as financial concerns raised by the analysis.

Public agencies acting to improve public health and welfare and environmental quality need to incorporate the externalities into their decision making.

Although the PCLTF died, the liability monetization algorithms were further refined in subsequent ICF studies. For the DOD, the monetization methodology was used to illustrate the "true costs" of waste disposal directly in landfills compared to other alternatives.[4] By making explicit a more complete range of costs, the report for the DOD spotlighted least-cost waste management strategies for fifteen DOD waste categories.[6] The report found that liability costs can and do influence the least-cost management options for five waste categories, including concentrated solvents and toxics. Liability costs tend to favor treatment and volume reduction over options with greater reliance on land disposal. Volume reduction is always part of the least-cost strategy.

In recent years, the monetization methodology has been expanded to include a more complete range of legal liabilities and better data on cleanup and compensation costs. Using its Bodily Injury and Property Damage Assessment Model (BIPDAM) to link the cost algorithms to radiation dose-response data, for example, ICF prepared risk/cost curves for the states of Washington and New York that described the probability that certain dollar amounts of damages will be exceeded for activities involving low-level nuclear materials and wastes. This allowed evaluation of alternative levels for financial assurance requirements.

In recent years, the monetization methodology has been expanded to include a more complete range of legal liabilities and better data on cleanup and compensation costs.

Other social costs. In addition to legal liabilities, pollution may impose other costs on society that are not well internalized by the manufacturers, sellers, and/or purchasers of the goods. These can include, for example: the difficult-to-measure costs of environmental degradation and diminished quality of life due to air pollution; cleanup or compensation costs not adequately covered by liability laws; other easier-to-measure losses, such as productivity losses, that may not be recoverable at law for many reasons; and costs incurred by taxpayers to support the administration of pollution control activities, including the inspectors, the permit writers, the bureaucracy, and its equipment. The last category of costs is relatively easy to measure, but not so easy to allocate. Unlike liability costs, not much work has been completed in this area, although some studies are underway to measure and assign public waste management costs to materials that end up as solid wastes, as described later in this article.

Risk Assessment and Life-Cycle Studies

Many analysts have performed studies comparing the relative risks of different types of energy sources, such as coal versus nuclear, attempting in some cases to assess the risks from "cradle to grave," a life-cycle concept applied to risk. In addition to assessing air emissions and wastes, such studies look at the mining, materials handling, and transportation risks associated with each energy source. In this way, a more complete "risk assessment" is produced, with the intention of informing policy makers to encourage substitutions.

Risk assessment is a tool frequently used in developing environmental protection standards that accomplish risk substitutions through legal (as opposed to economic) incentives. The key is to identify all risk-posing aspects of chemicals or processes through their relevant life cycle. First, "baseline risks" are assessed for current practices of production, chemical handling, or waste management; subsequently, the risks of alternative practices are assessed. Usually, the latter risks are lower than the former—that is, the point of establishing or tightening environmental standards. In some cases, however, risks subsequent to a potential regulation may perversely be enhanced. For example, in establishing regulations for the land disposal restrictions under the Hazardous and Solid Waste

Amendments (HSWA) of 1984, the EPA evaluated whether the alternatives (e.g., incineration) to land disposal of hazardous wastes posed greater risks for certain hazardous wastes. The EPA has conducted and commissioned scores of risk studies that vary in goal, focus, and comprehensiveness.

Under such environmental laws as the Toxic Substances Control Act, Clean Air Act, and Clean Water Act, EPA has applied risk assessment to chemical production and handling operations to characterize worker exposure, emissions, effluent and solid waste, and by-products. Marine and highway transportation risk assessment has been used to evaluate routing decisions by assessing exposed populations and accident probabilities; such studies use probabilistic risk assessment techniques to account for uncertainty. Likewise, to implement the Resource Conservation and Recovery Act (RCRA) and CERCLA, EPA developed and applied risk assessment techniques to alternative waste management practices, waste mixtures, and environmental settings, both generic and site-specific. RCRA is a "cradle-to-grave" law, addressing the full life cycle from waste generation to ultimate disposal.

Despite the development of guidelines for performing risk assessments over the past ten to fifteen years, linking these various existing elements together to develop a life-cycle risk profile for chemicals or products is problematic due to inconsistent and incompatible assumptions and approaches. Particularly with respect to the products or systems that are the focus of life-cycle costing approaches, much work remains to be done to develop an approach that produces useful risk estimates.

EPA has applied risk assessment to chemical production and handling operations to characterize worker exposure, emissions, effluent and solid waste, and by-products.

Recent Applications of Life-Cycle Analysis to Environmental Issues

A variety of research has been conducted using life-cycle studies as a method to compare the environmental impacts of competing products. A 1989 "resource and environmental profile analysis" attempted to account for the total energy and environmental impacts associated with soft drink packaging systems for the National Association for Plastic Container Recovery.[6] The study covered plastic bottles, aluminum cans, and plastic containers. Energy consumption and pollution were measured at many stages of each product's "life cycle," beginning at the point of raw materials extraction and continuing through processing, manufacturing, use, and final disposal, recycling, or reuse. Environmental impacts were expressed as air emissions, solid waste, and waterborne waste. The study concluded that polyethylene terephthalate (PET) containers are the most energy-efficient compared to aluminum or glass and that the PET containers contribute the smallest amount of solid waste by weight. Like all such studies, the assumptions, data, and analytic methodologies used must be carefully evaluated to have confidence in the results and their scope of applicability.

Another study, completed for the Council for Solid Waste Solutions, a plastics industry trade group, compared the energy and environmental impact of plastic bags with paper bags.[7] The study concluded that plastic bags were environmentally superior to paper because they produce 74 percent to 80 percent less solid waste, 63 percent to 73 percent less atmospheric emissions, and more than 90 percent less waterborne wastes. This study, unfortunately, only considered the quantity of pollutants released, which is a major limitation. Other factors that can contribute to a product being considered environmentally superior were not taken into account, such as the degradation rates of paper versus plastic, population exposure, and health/environmental effects. The analysis does not claim to be a risk assessment; no attempt is made to quantify risk. A similar problem limits the usefulness of a study comparing foam polystyrene (PS) and bleached paperboard cups, plates, and hinged containers.[8]

Also conducting extensive life-cycle analyses is the Tellus Institute, a nonprofit research group in Boston. The Tellus Institute, under contract to the New Jersey Department of Environmental Protection (NJDEP) and other agencies, is conducting a major life-cycle assessment of the environmental impacts of producing and disposing of packaging materials. Although the Tellus Institute is unable to draw conclusions regarding packaging materials at this point, they are looking ahead to the next step in their analysis, which will be to analyze the specific pollutants released from these products. NJDEP hopes that the study, which is expected to be completed next year, will provide the necessary data to prioritize products and packages in regard to their environmental impacts. In addition, the Tellus study will attempt to analyze the impacts of pollutants on human health. The issue of human health impacts is particularly important because, although one packaging material may produce less weight than another material, the pollutants released may be far more toxic (for example, the foam "peanuts" that off-gas ozone-depleting blowing agents).

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A task force set up in New Jersey in response to growing concern over solid waste issues recommended establishing a 60-percent recycling goal for products and recommended establishing criteria to phase out products not meeting that goal. In response to these recommendations, the NJDEP began using life-cycle studies to determine which products are environmentally superior and which should be phased out. One such project currently being conducted involves consideration of predisposal fees for packages and, in the future, for products. In theory, because the costs of environmental degradation of packages and products are not reflected in their prices, predisposal fees would remove disincentives for people to purchase products that will generate less waste, can be recycled or reused, or do not pose a threat of environmental degradation. Such fees will "level the playing field" so that environmentally "good" products can

compete with "inferior" products. Market forces, of course, do not guarantee that environmentally inferior products will eventually be phased out.

In addition, the NJDEP is also investigating the environmental and economic impacts of reusable systems compared to single-use packages. Although the NJDEP is doing some work focusing on waste-end fees, such as requiring tipping fees at certain landfills, this particular project and the majority of its work focuses on front-end fees. Although waste-end fees may sound good in theory, in practice waste-end fees may provide a disincentive for proper dumping at landfills and waste may end up being dumped improperly or in environmentally sensitive areas.

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Similarly, the State of California is in the process of developing recommendations (or legislation) for a disposal cost fee system to ensure that the individuals and organizations responsible for generating solid waste directly pay the full cost of solid waste management, including the costs of environmental degradation and state and local waste management programs. The California Waste Management Board has commissioned a study examining all types of goods and materials that are normally disposed in the state. Goods and materials with the greatest potential for environmental degradation will be determined using life-cycle approaches. These materials will then be charged an appropriate fee related to the material's solid waste management costs and costs of environmental degradation, as well as the current level of source reduction and recycling.

In summary, applications of the life-cycle concept to environmental issues have emphasized:

- Pollutant releases, rather than risks. Although risk assessment is more controversial due to its many necessary assumptions, it is the only analytic tool that can tell us whether less of one pollutant (i.e., fewer tons released) is preferable as a substitute for less of another.
- Alternative packaging systems rather than end-use products with substantial lives and significant ownership costs. However, because alternative packaging systems have little intrinsic value (we expect them to be rapidly disposed of once their function is complete), environmental impacts are a reasonable basis to establish preferences.
- Assessing and allocating externalized disposal costs to items comprising the solid waste stream, rather than the full spectrum of externalized pollution costs prior to disposal. However, it may be that much of the solid waste stream poses relatively minor environmental impacts prior to disposal. This needs more research.

Summarizing the Issues

Life-cycle studies are becoming increasingly popular methods for conducting cradle-to-grave analyses for particular products. However,

it is premature to consider life-cycle studies to be scientifically rigorous or comprehensive. Although researchers believe that life-cycle studies are necessary and important, particularly in regard to pollution prevention and control activities, and in helping to change people's habits, many researchers also believe that life-cycle studies can be inadequate and can lead to arbitrary conclusions. Life-cycle studies often have major methodological and data gaps, may be based on flawed assumptions, and currently do not fully portray a product's environmental effects. There is a need for more peer review.

Life-cycle costing is not itself costless. The gathering or estimation of cost data can be particularly time-consuming and burdensome. The mathematical analyses also must be performed and reviewed by specialists. Accuracy of results will often be questionable. Yet, although not perfect, life-cycle costing can be useful as a tool for comparing alternative products or systems, assuming rough equivalence in performance.

Life-cycle costing is not itself costless. The gathering or estimation of cost data can be particularly time-consuming and burdensome.

Many researchers believe that life-cycle studies are often misunderstood and consequently misused. Even though existing life-cycle studies do show certain comparisons between competing products, they are not yet comprehensive. Because the life-cycle approach to determining environmental impact is still growing and evolving, these studies cannot be accurately used to make broad generalizations regarding the environmental superiority of competing products. As research continues to evaluate the environmental impacts of various competing products and packaging systems, the methodologies of the life-cycle studies used to make these determinations need to be closely watched also.

Because pollution prevention should mean reduced risk, risk assessment must remain the primary analytic tool for assessing alternative practices, products, or systems. Thus, to substantiate government decisions designed to advance the public health and welfare and environmental quality by encouraging use of environmentally benign products and processes, a risk-based life-cycle methodology seems necessary to evaluate alternatives. Yet, absent legal compulsion or incentives, it is largely economics that will drive the decisions of businesses in purchasing and investment decisions. In this regard, the further development of life-cycle analysis in the direction of full-cost accounting is desirable, even if some externalities remain outside the frame of reference of the purchasing or investment decision. ♦

Notes

1. B.S. Dhillon, *Life Cycle Costing: Techniques, Models, and Applications* (1989). See also M. Robert Seldon, *Life Cycle Costing: A Better Method of Government Procurement* (1979).

2. ICF Incorporated, *Pollution Prevention Benefits Manual* (Volumes I and II) (1989).

3. ICF Incorporated, *Post-Closure Liability Trust Fund Simulation Model* (1984).

4. ICF Incorporated, *A Comparison of the True Costs of Landfill Disposal and Incineration of DOD Hazardous Wastes* (1984, draft)

5. ICF Incorporated, *Least-Cost DOD Hazardous Waste Management Strategies* (1987, final draft)

6. Franklin Associates, Ltd., *Comparative Energy and Environmental Impacts for Soft Drink Delivery Systems* (1989).

7. Franklin Associates, Ltd., *Resource and Environmental Profile Analysis of Polyethylene and Unbleached Paper Grocery Sacks* (1990).

8. Franklin Associates, Ltd., *Resource and Environmental Profile Analysis of Polyethylene and Bleached Paper Grocery Sacks* (1990).

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Economics of Pollution Prevention: How Waste Reduction Pays

Charles Rooney

Although most people usually think of waste as a problematic environmental issue, if viewed in a positive light, waste is the biggest opportunity manufacturers have to increase profits. Eliminating waste can improve product quality and the environment, but that is secondary to the money a company can save. This article shows how to measure the financial damage waste causes and explores methods that companies can use to find and eliminate the causes of manufacturing waste.

EVERYONE THINKS OF waste as an environmental issue. That's natural, but mistaken. Everyone also thinks it is a problem. That too is a natural mistake. Waste is a huge economic issue. It is also the biggest opportunity North American manufacturers have ever had to increase their profits. By eliminating waste, any company will improve the quality of its products and the environment, but that is secondary to the enormous amount of money the company will make.

The top industrial managers are beginning to recognize this. On June 11, 1991, *The Wall Street Journal* ran a front page article, "Chemical Firms Find that it Pays to Reduce Pollution at Source." The article discusses the savings that Dow, Du Pont, and Monsanto have made by cutting waste.

The Du Pont case makes the critical points. To quote: "Du Pont engineers argued that reducing the pollution would be too expensive. But when they took a second look last year, they found just the opposite was true. By adjusting the production process to use less of one raw material, they were able to slash the plant's waste by two-thirds. Yields went up and costs went down. The savings: $1 million a year . . . . Edgar Woolard, Du Pont's chairman and chief executive officer, says the company now even sees waste reduction as a way to achieve a competitive advantage."

This article shows how to apply the lesson these managers have learned: Waste reduction pays. It demonstrates first that waste is a huge cost in most businesses. Then it presents good evidence that waste is not an inevitable cost of doing business. Any company can increase profits quickly and permanently by cutting waste. Third, it introduces a simple methodology for measuring the economic damage waste causes. Finally, the article deals with ways to find and eliminate the causes of waste in manufacturing processes.

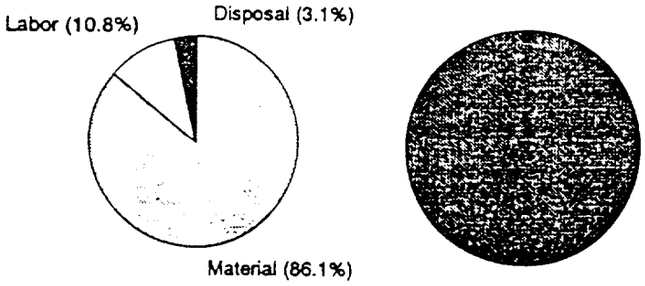
The Cost of Waste

It is simple, in principle, to calculate how much waste costs an industrial company. All one has to do is add up four elements:

Dr. Charles Rooney is president of Orr & Boss, a manufacturing consulting firm located in Plymouth, Michigan, that has specialized for twenty-five years in helping companies increase profits by implementing effective pollution prevention and continuous improvement programs.

Figure 1. The Cost of Waste in Three Businesses

Fiberglass Pipe
Cost of Waste and Plant Labor

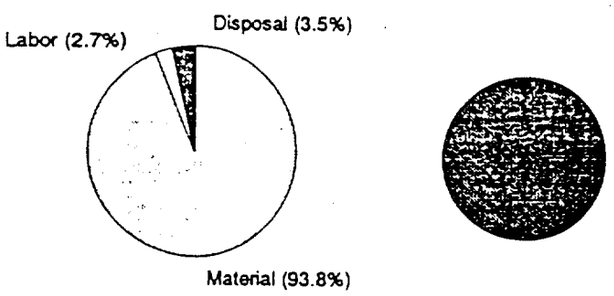


Cost of Waste
$1.443 million a year

Plant Labor
$1.837 million a year

This plant manufactured glass reinforced epoxy pipe for the oil and gas industry. The pipe was made by a sophisticated proprietary continuous process. Continuous processes are often more wasteful than management suspects.

Pressed Plastic Parts
Cost of Waste and Plant Labor

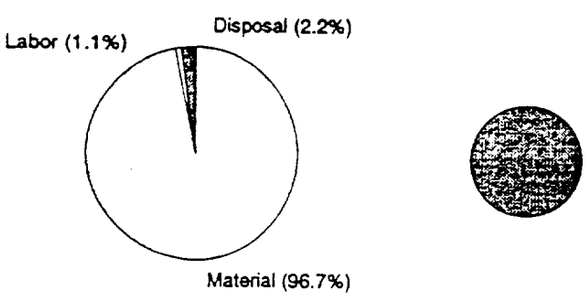


Cost of Waste
$4.296 million a year

Plant Labor
$2.746 million a year

Automotive trunk liners and similar parts are made at this plant by bonding carpet to an extruded plastic sheet. The key process was a combined pressing and die cutting operation.

Painting Fascias
Cost of Waste and Plant Labor



Cost of Waste
$23.15 million a year

Plant Labor
$6.65 million a year

Spray painting is always wasteful. This example shows what can happen in a modern plant with the best electrostatic equipment and spraying robots.

Raw material

First, there is the cost of the raw material in the waste. Manufacturers buy the raw material in every piece of scrap or gallon of effluent. They intend to use it to make salable product. When the raw material becomes waste, the manufacturer loses the material's value.

Nobody buys material just to throw it away. By the time it becomes waste, the factory will have worked on it. Thus, all waste contains labor. The value of that labor is also lost, as is the labor used to rework unsalable product.

Labor

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Disposal

Disposal charges are clearly an expense that springs from waste. In most companies they are the only element of waste-related expense that is recognized explicitly. As landfills close, garbage disposal costs mount. When the waste is legally hazardous, the disposal charges are exorbitant.

Waste handling

This figure has two elements. First, the plant will use labor to collect and store its rubbish. It may also process its garbage, for example, by compacting solids, or distilling liquids. The expense of running these operations is a result of making waste. Secondly, disposal is tightly regulated. It imposes a costly administrative burden. This is particularly true when hazardous chemicals are involved.

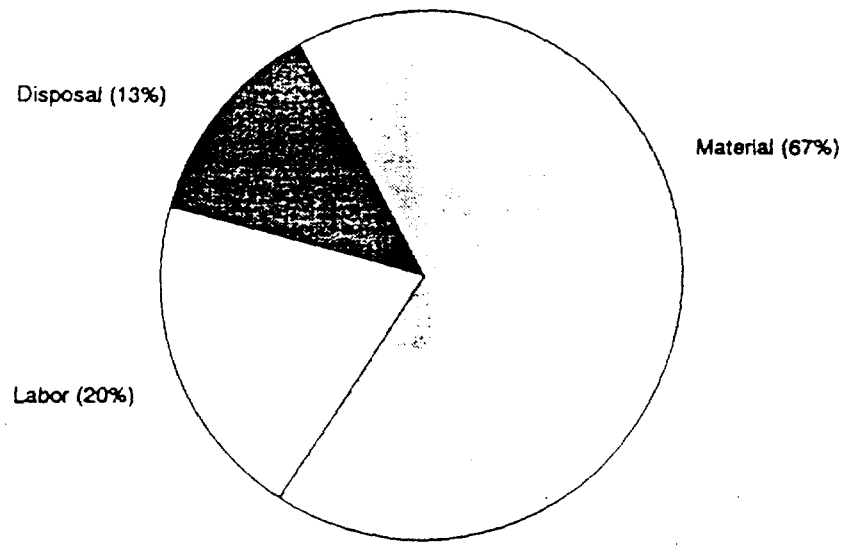
Figure 1 shows the result of combining these four elements into a cost of waste (analogous to the cost of quality) for three different businesses. Disposal and internal waste-handling charges are combined in all three cases.

Figure 1 leads inevitably to two conclusions. First, waste is expensive. It costs more than direct labor in most manufacturing operations. The excess expense caused by waste is very seldom less than half the direct labor cost. It is often several times as large. That means that if waste can be reduced (i.e., if it is not an inevitable cost of doing business), it is the biggest opportunity to increase profits in most North American plants.

The second conclusion is that waste costs money because the plant loses raw material. Labor is a small part of the total. Disposal and waste handling are trivial. This is even true in the chemical industry where disposal is costly because most of the wastes are hazardous. (**Figure 2**, which analyzes waste-related expense at eighteen North American chemical plants, confirms this point.)

To save money on waste we have to avoid making it. Treating it afterwards is not the answer. That can only influence disposal, which is a tiny fragment of the total. Minimizing the cost of waste is a question of optimizing raw material utilization.

Figure 2. Analysis of Waste-Related Expenses at 18 Chemical Plants



That lesson is also important for the environment. There are no good ways of disposing of waste, only bad or worse ones. The slogan "Reduce, Reuse, Recycle" recognizes that environmental truth. To recognize the economic truth, the slogan should be "Reduce, Reduce, Reduce."

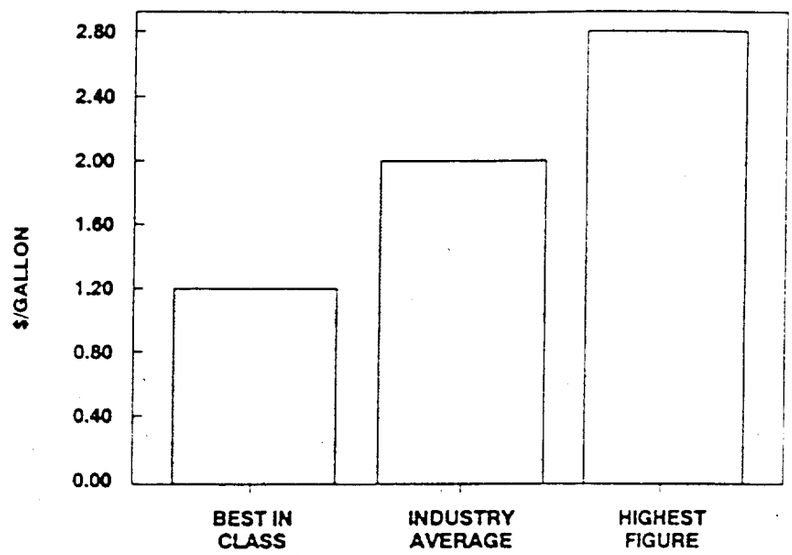
Competing through Pollution Prevention

In the past, many managers regarded waste as a cost of doing business. They felt it was inevitable, or uncontrollable. Sometimes, like the Du Pont engineers, they argued that reducing the pollution would be too expensive.

The truth is exactly the opposite. The right process changes reduce material losses quickly and permanently. These changes are not normally expensive. They do not usually require significant capital investment. What they require is a change in attitude. That change is a return to looking at the facts of the business on the factory floor.

The North American automotive OEM coatings industry provides striking quantitative support for this argument. It is a good example because the industry is so homogeneous. The main players are three major chemical companies: Du Pont, PPG, and BASF. Each of the three has several plants. All the plants use essentially the same production processes and equipment. They buy from the same suppliers and sell to the same customers. Yet **Figure 3** shows there is a startling difference in waste costs among plants. The lowest-waste

**Figure 3. Automotive OEM Coatings—
Cost of Waste in Dollars Per Gallon of Good Production**



plant spends $1.60 less on waste per gallon of product sold than the worst plant. This difference is within a few cents of the industry average for labor cost per gallon. That must be considered a significant competitive cost advantage.

Calculating What Waste Costs

Table 1 shows the way most accounting systems divide up the cost of waste: (1) the value of the raw material in the waste, (2) the labor loss, (3) disposal charges, and (4) internal cost of waste handling. Our aim is to provide a quick way of calculating what waste actually costs a company. The methodology uses figures available from nearly all standard costing systems to calculate an overall cost of waste. This cost of waste is analogous to the cost of quality defined by Armand Feigenbaum, but simpler. It is designed to be a sober, conservative measure of the hard costs of wasting material. It is possible to determine the cost of waste in a typical plant in two or three days.

Valuing explicit and implied losses

The only part of the calculation that poses any difficulty is deriving the value of the part of the raw material losses that is built into the standard costs of the products. It is critical to get that number right, because it usually represents the largest component of the cost of waste. Nearly all the other figures—the variances, write-offs,

Table 1. Cost of Waste

Components of Cost of Waste	*Form in Standard Costing System*
Material losses	Material loss allowances in standards, explicit and implied
	Material usage variances
	Scrap, obsolescence, rework, and other special loss accounts in the central ledger
Labor losses	Labor in scrapped, reworked, or otherwise discarded product
Disposal charges	Payments to outside disposal contractors from GL
Waste handling expense	Normally must be estimated from the number of staff employed in waste handling and reporting, using conservative wage and salary rates

labor, and disposal charges—are available directly from the cost accounting department. Thus, this article deals only with ways of valuing explicit and implied standard loss factors.

Virtually every costing system builds material loss allowances into product costs. (During twenty-five years of pollution prevention practice in eleven countries, we have only encountered one that did not.) These allowances are designed to reflect the historical level of material waste generated by manufacturing the company's products. Budgets and prices should be based on standards that include these allowances in order to reflect current reality. The fact that the losses are built into the standard, however, does not mean they are inevitable. If accounting budgets to use six pounds of raw material to make five pounds of product, the plant is budgeting to waste one pound. That pound is waste whether it is built into the standards or reported as a variance. Unfortunately, if it is built into the standard, it will become invisible to management, as though it cost nothing.

Most costing systems use explicit and implied cost allowances. Explicit loss allowances are stated directly on product cost sheets. They have names like manufacturing loss allowance, process loss, shrinkage factor, or scrap factor. For the most part, they are expressed as a percentage of the raw material actually used to make the product. When a product goes through several manufacturing steps (e.g., molding, trimming, painting, and finishing), the standard cost will often introduce explicit loss allowances at each step.

By definition, implied standard loss allowances are not stated openly on the cost sheet. They take the form of a standard cost that states that the product has more parts in it or weighs more than it

Table 2. Illustration of Explicit and Implied Standard Losses

Extract from Standard Cost of XXXX Rear Panel Showing Explicit Loss Factor

Input plastic blank weight	4.86 lbs
Manufacturing loss allowance (2%)	0.10 lb
Total standard plastic usage	4.96 lbs
Parts per blank	2
Standard plastic usage per part	2.48 lbs
Explicit standard loss allowance per part	0.05 lb

Comparison with Actual Weight of Part at Dimensional Standard Calculation of Implied Loss Allowance

Actual weight of plastic in a part at standard thickness, width and length	1.15 lbs
Total difference between standard usage and actual part weight - total standard loss allowance	1.33 lbs
Part stated explicitly on cost sheet - the explicit allowance	0.05 lb
The remainder - the implied loss allowance	1.28 lbs
Percentage implied loss for this particular part	51.6 %

actually does. Implied losses can only be determined by weighing or measuring the product and comparing reality with the costing.

The differences may be obvious (e.g., costing three bolts into an assembly that uses two), or they may be more difficult to detect. For example, in a rotary casting operation, the standard costings allowed 2.1 pounds of material per piece. The finished castings, after being ground to standard size, weighed just under one pound. The additional waste built into the standard was sent to a landfill as grinding dust or reject parts.

Table 2 shows how the costing system at the automotive trunk liner plant, mentioned in Figure 1, applies explicit and implied loss allowances. Following this example, it becomes apparent how much the cost of waste is hidden by current accounting practices.

The top half of Table 2 shows how the accountants arrive at a standard usage of 2.48 pounds per plastic part. They have done so by weighing the blanks fed into the press and allowing a 2 percent, or .05 pound explicit loss allowance per part for defects or damage. As shown in the bottom half of the table, however, the actual weight of the

Table 3. Elements of the Cost of Waste in the Trunk Liner Plant

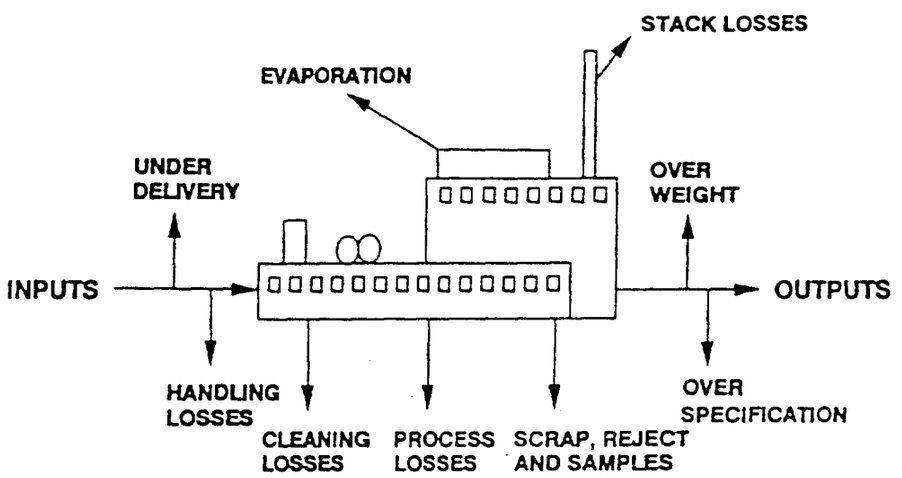
Element	*$000/Year*	*$000/Year*
Material		
Losses built into standards	4,026	
Material usage variance (gain)	(455)	
Material content of scrap	198	
Inventory loss	261	
Total material losses		4,030
Labor		
Labor in scrap	117	
Total labor		117
Waste Handling and Disposal		
Internal waste handling labor	43	
Disposal	106	
Total waste handling and disposal		149
Total Cost of Waste		4,296

plastic in the part is only 1.15 pounds. The rest of the plastic, 1.28 pounds per part (51.6 percent of the material input) is lost as edge trim or offal. This implied loss is built into the standard cost and will not show up in any financial reports. Thus, in most companies, the accountants themselves will be unaware of these losses.

To calculate the total value of the material losses built into the standards, it is necessary to multiply the total value of raw material throughput by the weighted average standard loss allowance percentages. In the trunk liner factory, all the parts had a 2 percent explicit loss allowance. Implied loss varied from part to part: The highest was 63.6 percent and the lowest was 28 percent. On average the standards contained an implied loss allowance of 43.7 percent. Thus, the total standard loss allowance for an average part was 45.7 percent of the material input. Put another way, by performing at that standard, the plant was wasting 45.7 percent of material input.

Table 3 shows the total cost of waste for the trunk liner plant. Material losses built into standard costs account for 93.7 percent of the total cost of waste, or $4.026 million out of a total of $4.296 million a year. This standard loss does not appear in routine financial reports on plant performance. Thus, normal accounting reports underestimate the opportunity to increase profits through pollution prevention by a factor of fifteen.

Figure 4. Physical Material Losses



This trunk liner plant is an extreme example, but it illustrates a universal finding. The cost of waste in most plants is between five to seven times higher than management or environmental professionals realize.

Eliminating Waste

Although the cost of waste derived from the accounts will be correct in aggregate, it has no practical use in directing waste reduction activity in the plant. Knowing that the accounts deal with the value of a waste stream through a manufacturing loss allowance tells nothing about the form or cause of that waste. Therefore, the first step in any waste reduction project is a careful physical measurement of material losses in the plant. Second, it is important to realize that all useful measurements involve tracing the waste stream to its source. The object of the measurement is not to characterize the waste for transport, treatment, or, disposal, but to find what causes it.

It is useful to divide the waste leaving a plant into nine categories of material loss. These categories define the source of the waste and indicate broadly the type of action that will be necessary to minimize it. **Figure 4** shows the model. It is suitable for most production processes. The nine categories of loss can take an amazing number of forms. **Table 4** presents some examples of common forms and ways they can be measured.

Three of the losses in Figure 4—under delivery, over weight, and over specification—do not appear as physical waste streams. They

Table 4. Nine Categories of Material Loss

Category of Loss	*Examples of Loss*	*Examples of Measurement*
Under Delivery	Short weight in containers, tankers, or rail cars	Weigh samples of high usage value materials.
		Weigh tank trucks in and out of plant using certified scale, close to the plant, under plant supervision.
		Inspect rail cars to see if they are completely empty.
	Higher than standard water or solvent content in solutions or emulsions	Take samples and have solids content measured.
		For milk or other food ingredients measure fat content as this is often the expensive component of the mixture.
Handling Losses	Burst or cut bags	Timed inspection of raw material storage to determine rate at which containers are damaged.
	Material left in bags or drums	Shake, scrape, or wash out containers emptied in production. Weigh the empty containers to find the loss by difference.
	Damaged product	Set up temporary quarantine areas and segregate any product damaged badly enough to require repair or to be scrapped.
Process Losses	Set up pieces	Observe the start of production and collect or measure the start up loss.
	Chips machined off parts	Weigh blanks, raw castings or forgings, then weigh the finished parts. Find the loss by difference.
	Sanding dust	Weigh the dust from a known number of parts or time of production.
	Off cuts, edge trim, offal	Weigh blanks, or sheets or rolls of raw material input. Then weigh the parts, and if possible offal as a check.
	Product left in mixing vessels, mills, tanks	Scrape or wash out the equipment. Calculate the loss from the weight of product left after each use, and the number of uses a year.
		It is unusual to find good records of process losses. They must usually be observed on the factory floor. These observations may sometimes be cross checked in process industries against yield records, or hazardous waste reports.
Cleaning Losses	Solvent, resin or detergents used to clean equipment after production	It is unusual to find good records of cleaning losses. They must usually be observed on the factory floor. These observations may sometimes be cross checked in chemical plants using hazardous waste reports.

Quality Losses	Scrap	The accounting or plant production records for the first five losses usually give fairly accurate quantities. They will not normally give good information on the cause of the loss. That may be available by correlating QC/QA records with production records for the same period.
	Customer returns	
	Rework	
	Seconds	
	Obsolescence	
	Samples	Sampling loss can be estimated from the size and frequency of QC/QA sampling. Often there is only verbal evidence of this.
Evaporation	Unexplained solvent loss	Evaporation is hard to measure and much smaller than usually thought. The great majority of unexplained solvent loss is unauthorized use for cleaning. True evaporation can be found by mass balance or by vapor content and air velocity measurements. The mass balance is more reliable.
Stack Losses	Dust in bag houses	Weigh the dust collected over a sufficiently long period (several weeks), express as a percentage of production passing through the affected pieces of equipment.
Over Weight	Excess weight in packets	Weigh containers, packets, parts, candy bars, or other product in the finished, goods warehouse. Weighing in the packing or filling area will change the operators' behavior and invalidate the results.
	Excess volume in containers	
	Individual pieces weigh more than standard	Analyze SPC charts or other product weight records.
Over Specification	Excess of expensive component in product	This is a difficult loss to measure. It is always product specific. It can only be estimated by physical or chemical analysis of actual production.
	Candy bar with higher than standard chocolate to center ratio	Weigh centers entering enrober and weigh completed bars. Calculate ratio and cost difference from standard center and chocolate cost.
	Paint with higher than formula pigment content	Compare standard and actual solids content or specific gravity.
	Excess vinyl thickness on wallcovering stock	Weigh reels before and after coating.

are, however, included in the definition of waste for two reasons. First, they are losses of material value from the process. They cost money, even if they do not end up in a landfill. In addition, because they are losses of value, they are automatically included in any calculation of the cost of waste. It is useful to be able to reconcile the waste measurements from the plant with the accounting figures. That reconciliation provides a check on the accuracy of both figures.

Once the causes of a waste steam are known, the next stage is to ask five questions about it:

1. How can the production process be changed to *reduce* the amount of the waste that it generates?
2. How can the waste be *reused* in the same product without loss of value?
3. How can this waste stream be *reprocessed* internally into another product?
4. Can another company use or *recycle* the waste?
5. How will the plant *control* the generation of this waste in future?

The paragraphs below illustrate each of the questions with actual examples.

The first question for every waste stream must be "How can this source of waste be reduced or eliminated?"

Reduce

The first question for every waste stream must be "How can this source of waste be reduced or eliminated?" Reducing waste saves the most money because the company never loses the material value of the waste stream; it remains in the product. The plant never has to expend labor to handle the waste. Finally, reducing waste increases capacity.

For example, in the fiberglass pipe plant (see Figure 1), machine start-up caused half of the scrap. To address this problem, a series of process changes were made. They included heating the curing ovens before start-up; double crewing and starting half the machines at a time; and following a specific, detailed start-up procedure. These changes cut start-up scrap from 700 feet per machine to 25 feet. The time to reach full output dropped from 8 hours to 2 hours.

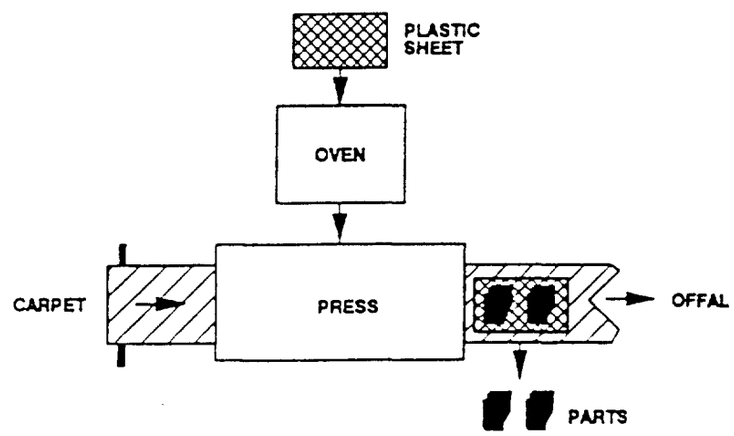
This exercise in source reduction also reduced labor cost per foot of good product, increased output, and saved $450,000 a year in scrap. There was no capital investment.

Reuse

Sometimes it is impractical to reduce the volume or value of a waste stream. Then the question becomes "How can this waste be reused as raw material in the product that created it?" This is less desirable than reducing the waste generated, only because reuse will involve double handling.

A very good illustration of reuse comes from automotive OEM

Figure 5. Illustration of Pressed Plastic Parts Process Flow



paint production, specifically, a plant that made a number of high viscosity mill bases in ball mills. In this plant, as much as 30 percent of each batch remained in the mill as a cleavage loss.

The plant reduced the loss somewhat by running several batches of the same product in a series before cleaning the mill. This technique cut the loss as a percentage of production volume, but it was not entirely satisfactory. The material carried over from batch to batch deteriorated due to excessive residence time in the mill. In addition, the production campaigns reduced flexibility and increased inventory.

The solution was to wash the cleavage out of the ball mill using a resin and solvent mix. (Using a mix prevented quality problems when the waste was reused.) The plant stored the wash in portable tanks. It was then used as an ingredient the next time the plant made the same mill base. This saved material worth $220,000 a year. The savings was only possible, however, at the expense of handling and storing the waste.

Internal reprocess

If reuse fails, then the question should be "How can the plant reprocess the waste, or recycle it internally, into another product?" Reprocessing does not normally save as much as reuse, because part of the value of the waste as raw material is lost.

The production of plastic and carpeted trunk liners provides an elegant example of the advantages and disadvantages of reprocessing. **Figure 5** shows the production process. Offal, trimmed off carpet and plastic, was the main waste stream in that plant. The die and press designs fixed the width of the carpet and the size of the plastic blanks. Reducing waste from current products would have required

prohibitive capital investment. Similarly, there was no way to reuse odd-sized off cuts.

The solution was to regrind the offal. This produced raw material for new plastic blanks. This recovered the value of the plastic, but the carpet was lost. It also required investment in grinders and a regrind handling system. The net saving was approximately $1.1 million a year out of a waste stream valued at $3.85 million a year. Clearly, reprocessing was better than throwing the offal away, but fell far short of the savings available from avoiding the waste.

Many industries reprocess their waste. The classic examples come from candy and paint. Coffee Crisp and Mars Chocolate bars both incorporate reworked product in their centers. Paint makers produce primers that contain scrap topcoat, still bottom sludge, or dirty wash water. In every case, the reprocessed material goes into a cheaper product or component of a product.

External recycle

When the waste cannot be reprocessed in the plant, selling or true recycling are the only options. This may involve paying another firm to convert the waste to a form that your plant can use. It may mean selling or even giving the waste to another company that can use it. Typically, recycling recovers only a small fraction of the value of the raw material in the waste.

Redistilling waste cleaning solvent is a good example of recycling. Chemical and coating companies generate dirty solvent when cleaning production equipment. In an industrial coatings company, this mix of solvent and paint will have a material value close to $2.20 a gallon. Typically, solvent reclamation will recover mixed solvent with a yield of 70 percent. The recovered solvent can be used for cleaning and will replace solvent costing $1.25 a gallon. Thus, each gallon of waste will generate solvent worth $0.88. Distillation charges, freight, and disposal of the still bottoms will cost between $0.80 and $1.03 a gallon of waste processed. Thus, the value of the recovered solvent comes close to netting out with the cost of recycling. That is better than paying to have the solvent burnt in a cement kiln, which typically costs between $0.28 and $0.57 a gallon. It falls far short, however, of the possible savings from reduction or reuse.

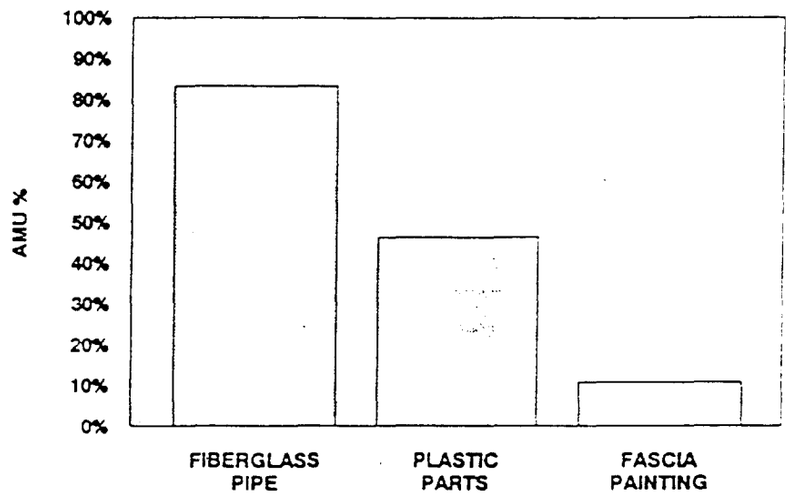
The last step of the waste reduction process is to introduce controls. Without simple, timely control reports, waste soon returns to its original level.

Control

The last step of the waste reduction process is to introduce controls. Without simple, timely control reports, waste soon returns to its original level.

The cost of waste has three defects as a control measure. First, it is a financial figure. Operators and supervisors find physical figures relating to the pounds, gallons, or pieces they handle more meaningful. Second, it is not timely. It can be estimated each month, but the figure is only accurate just after physical inventory. Factory floor waste control needs daily and weekly numbers. Finally, it is not

Figure 6. Aboslute Material Utilization Percent



usually possible to calculate the cost of waste for individual departments or areas of the plant.

The weaknesses of the cost of waste can be overcome by using another measure of waste, the absolute material utilization ratio (AMU). This is the ratio of the material that is absolutely needed in the goods' output to the material actually used in production. Figure 6 shows the absolute material utilization ratios of the plants used as examples in Figure 1. It is immediately apparent that the AMU is a good proxy for the cost of waste. The higher the cost of waste as a proportion of total direct cost, the lower the AMU. That is a simple consequence of material losses being a high proportion of the cost of waste.

Anybody can understand the AMU. It is an obvious measure of the effectiveness with which a process, plant, or company converts raw material into finished product. If the AMU is 80 percent, the process converts 20 percent of its input to waste. It can be calculated for any process or department as long as the amounts of material input and physical waste are known. It is easy to calculate for short periods, a day, or a shift. Thus, it fulfills all the important requirements and is the best control measure for waste.

Organizational Levels for Reporting Waste

Most organizations need three levels of waste reporting. The first stage is hourly collection of material loss data from major operations. It is cheap and convenient to use hand-held computers to accumulate

the data and produce the reports. The first line of control is plotting waste levels or yields on statistical process control charts. The purpose of the charts is to trigger immediate investigation and corrective action. They are used primarily by line operators.

The second level is daily yield and quality reporting by department or production process. These reports will also contain weekly or monthly figures. They are aimed at departmental management and supervisors who use them to identify targets for improvement.

The third level of reporting is a series of monthly summaries of the lower-level reports by department, consolidated to a plant-level report. These should be reconciled quarterly with the actual waste shipments leaving the plant and the waste levels implied by the accounts. This level of reporting helps manufacturing management to track progress, and decide on the level of resources to allocate for pollution prevention.

Following the six steps—reduce, reuse, internal recycle and reprocess, external recycle, control, and reporting—starting with the largest waste streams, should allow companies to cut the cost of waste by 30 percent within a year. Continuing for another two years will save another 20 percent of the original figure. With the right controls and attitudes, waste will continue to decrease in subsequent years.

The Economic Impact of Pollution Prevention

North America leads the world in per capita production of garbage. The continental cost of waste has never been measured, but it is possible to estimate its order of magnitude. Waste costs more than labor in most manufacturing operations. National statistics show that U.S. manufacturing has 18.2 million hourly paid employees. Their average hourly wage is over $12. Simple multiplication suggests a cost of waste in the $400 billion a year range. Active pollution prevention can halve that, saving every North American $800 a year, and at the same time, improve the environment.

Minimizing the cost of waste is a question of optimizing raw material utilization.

The first step in cutting North America's continental cost of waste is absorbing three concepts stressed in this article. First, waste destroys profits. This is true for any manufacturer in any industry. Second, it can be reduced cheaply, quickly, and permanently. It is not an inevitable cost of doing business. Third, to save money on waste, we have to avoid making it. Treating it is not the answer, economically or environmentally. Minimizing the cost of waste is a question of optimizing raw material utilization.

Eliminating industrial pollution will be slow. It will have to be tackled process by process and plant by plant. One of the best ways for any manufacturer to start is to devote a few days to measuring the cost of waste in one plant. The result will be a surprisingly large opportunity to improve profits. The next step is physical waste measurement. Then the hard work starts. Take each waste stream, study its source, and "Reduce, Reduce, Reduce." ◆

 MBAA Technical Quarterly, Vol. 30, pp 114–117, 1993

Wastewater Minimisation and Effluent Disposal at a Brewery

By Colin Watson

ABSTRACT

The case study presents experience gained whilst conducting a water and wastewater audit for a brewery in order to identify short-term options for in-process waste reduction and to assess the brewery's long-term effluent treatment and disposal options. Sampling and flow monitoring of the main effluent streams were carried out to ascertain current flows and pollution loads. Discharges from individual process units were sampled manually to aid identification of the major sources of high pollution loads. Within each unit operation, water re-use and waste treatment/reduction alternatives were looked at to help formulate a cost effective waste management plan. Long-term effluent treatment and disposal options were then considered for the whole brewery site. By estimating the expected reductions in effluent flow and pollution loads, costs were calculated to show the benefits that would be gained by instigating water re-use and waste reduction measures.

SINTÉSIS

Este estudio presenta la experiencia ganada mientras se conidujo una auditoria de agua y aguas servidas de una cerveceria para identificar opciones a corto plazo para reduccion de desperdicios de proceso y para evaluar las opciones a largo plazo de la cerveceria para el tratamiento de efluente y manejo de desperdicios. Se llevo a cabo muestreo y control de flujos de las vias principales de efluente para determinar niveles actuales de flujo y polucion. Se utilizo muestreo manual de descargas y procesos individuales para ayudar a identificar las fuentes principales de cargas altas de polucion.

Dentro de cada unidad de operacion se evaluo alternativas de re-uso de agua y tratamiento/reduccion de desperdicios para ayudar a formular un plan para el manejo de estos puntos que sea eficiente en relacion a su costo.

Luego se consideran opciones a largo plazo para tratamiento y disposicion de desperdicions para la cerveceria entera. Estimando las reducciones de efluente y carga de polucion se calculo los costos para demonstrar los beneficios que se tendria al instigar re-uso de aguas y medidas para reduccion de desperdicios.

INTRODUCTION

The following case study describes a typical effluent audit/reduction study carried out at a brewery by ASHACT Ltd.

BACKGROUND

The modern brewery produces beer in bottles, kegs and bulk tankers. Considerable volumes of effluent containing high chemical oxygen demand (COD) and suspended solids (SS) concentrations are produced as a result of washing of vessels and associated equipment between batches. Effluent flows and pollution loads have increased significantly with production increases, resulting in consent limits for discharge to the public sewer being exceeded on a regular basis.

The water company had recently indicated that the brewery flows could continue to be accepted to sewer and the normal trade effluent charging system would be applied whereby charges varied according to variations in flow and pollution loads.

The current trade effluent charges amount to several hundreds of thousands of pounds per annum. After considering the likely implications of the increase in effluent charges, the company decided to appoint ASHACT Ltd, a firm of consultants, to carry out a study to investigate the possible ways of minimising effluent disposal costs. The audit team considered that the cost of effluent disposal at the brewery could be minimised in two ways:

- reduction in volume, COD and/or SS load of the effluent produced at source; and
- reduction in the COD and/or SS load of the effluent discharged to sewer by pretreatment.

PREASSESSMENT

Two ASHACT staff were allocated to carry out the required investigations, assisted as necessary by one of the brewery's technologists. With the help of the brewery's engineering staff, V-notch weirs were installed in manholes where all the various effluents combined so that the flow could be monitored continuously using ultrasonic level/flow meters and associated data loggers. Flow-proportional daily composite samples were collected using automatic samplers. The brewery's own laboratory was able to carry out the required effluent analyses.

In order to put the brewery operations in perspective from a waste management viewpoint, a preliminary check on effluent and pollution loads discharged per cubic metre of beer produced was carried out based on past records of water usage and product data together with some limited information on combined effluent strength. These are shown in Table 1 below.

It was concluded that, in general, the brewery operated with a very low degree of water wastage with most of the useful by-products or wastes already being recycled or recovered for off-site disposal. These aspects had been considered at an early stage in the design of the brewery and had clearly paid dividends in

Table 1
Effluent Contributions from Beer Production

	Actual	Typical Brewery	Old Brewery
Effluent Flow (m^3/m^3 beer)	2.1	7.0	18.0
COD Load (kg/m^3 beer)	7.1	4.5	15.0

Mr Watson graduated from Heriot-Watt University, Edinburgh, Scotland with a first class Honours Degree in Chemical Engineering. He joined Pilkington Glass Ltd and worked in the float glass production department and as a technologist in the development department.

He left the company in 1990 and joined ASHACT Ltd, a consultancy specialising in process and environmental management. Mr Watson, now a chartered chemical engineer, is responsible for many of ASHACT's projects including environmental auditing, waste minimisation, discharge sampling and monitoring programmes, contaminated land assessments and pollution abatement equipment evaluation. Recent projects have spanned a broad range of industries including brewing, papermaking, food processing and chemical manufacturing.

reducing effluent volumes and pollution loads discharged. Nevertheless, it was considered that there was still scope for further waste saving measures to be implemented.

Another factor in favour of this brewery is that most of the beer is transported in road tankers rather than bottles or kegs, both of which give rise to more effluent being produced.

The study team started off the effluent audit/waste reduction programme by becoming familiar with all the various production stages. This was done by walking around the plant with the brewery technologist and collecting relevant information from departmental records.

Schematic flow diagrams were drafted to illustrate the various unit operations that contributed to effluent discharges. An example for the kegging hall is shown in Figure 1. Once all the unit operations had been identified and described, the audit team proceeded to gather data on water usage, effluent output and waste recovery.

QUANTIFICATION OF WATER USAGE AND EFFLUENT PRODUCED

The principal process outputs of concern were the effluent discharges arising from production operations. It was also noted that minor domestic sewage contributions discharged to the same drainage network as the brewery process effluent. The audit team then proceeded to quantify these outputs.

The total effluent flow recorded during a two-week monitoring period averaged 1,400 m³/d. It was noted, however, from the flow patterns during each day that discharges were extremely variable with a peak flow rate of up to 80 m³/h. On the basis of this and a number of other assumptions, the audit team estimated that the maximum flow on any one day could reach 2,100 m³/d.

An estimate of domestic water usage and hence domestic sewage discharges to the trade effluent drainage system were also made; this was determined as only 5 m³/d (75 employees at 70 litres per head per day).

Each effluent source was quantified in terms of volume and pollution load. This involved sampling and flow measurement of individual discharges around the brewery. Since the volume and composition of some of these discharges varied considerably with the type of beer produced, the survey was undertaken over several weeks to allow a realistic assessment of the situation to be made.

The material balance with respect to overall effluent generation compared to the sum of the point sources showed a remarkably good agreement: the average daily combined pollution loads amounting to around 10% above the individual sources assessed.

On studying the volumetric data collated, and comparing this to the water usage records it appeared that around 7% of the water was unaccounted for (after making allowances for water in the product). It was observed that no allowance for evaporation had been included in the water balance and that, from ASHACT's previous experience of brewery operations, evaporation alone could account for up to 5% of total water usage. This allowance therefore effectively closed the small difference between water input and output indicated.

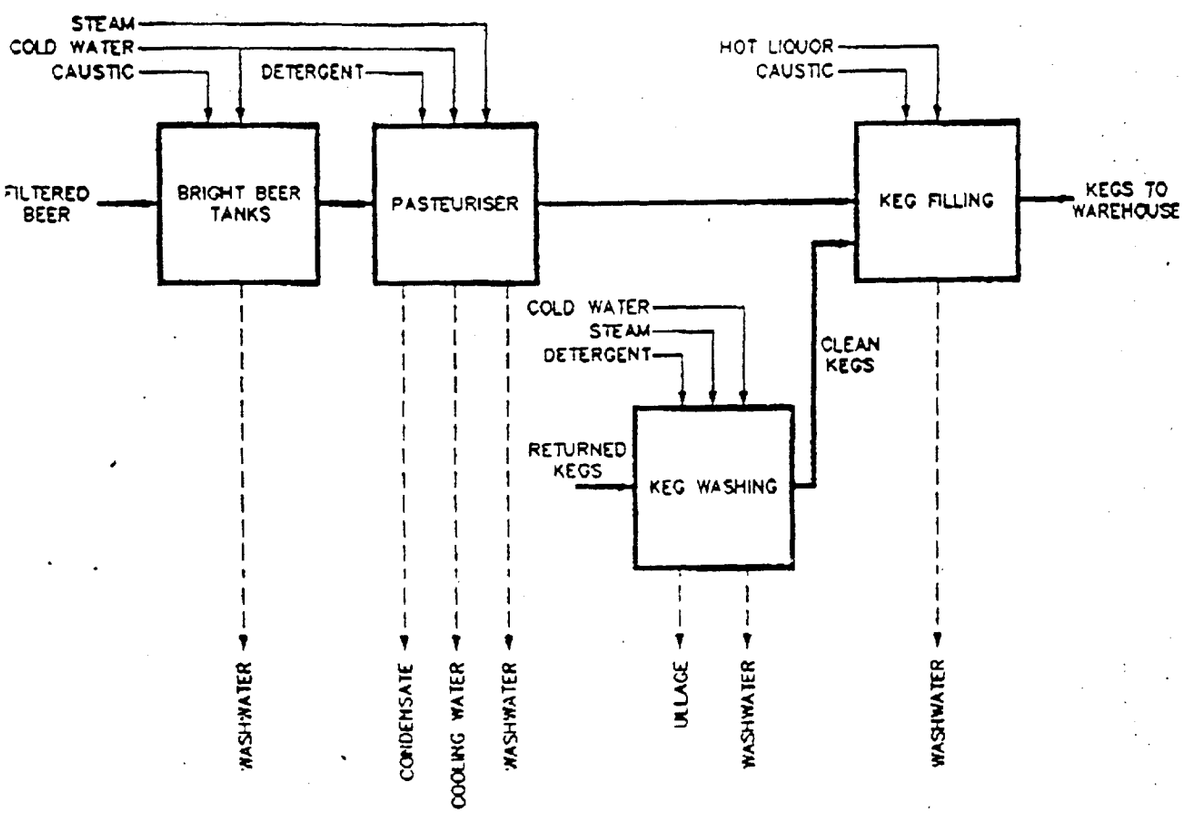


Fig. 1. Kegging Hall Schematic Flow Diagram Showing Discharges To Effluent.

EVALUATION OF EFFLUENT REDUCTION MEASURES

In the light of a comprehensive examination of the waste producing areas, it was possible to identify the major sources of effluent at the brewery. To assist the investigations into reduction possibilities, reference was made to available information (including database) sources, as well as ASHACT's own experience of undertaking similar projects. The various sections of the brewery were studied in turn as follows.

Brewhouse

The two principal discharges in the brewhouse were the drain from the Lautertuns and a hot liquor tank (70–80°C water) overflow. Together these contributed over 10% of the total effluent flow from the brewery.

[redacted] for [redacted] and that this should be possible without detriment to brewing standards. This would reduce raw water costs, eliminate effluent charges previously incurred by this discharge, reduce energy requirements and eliminate existing shock load discharges from this source which should remove any need for flow/load balancing of the total site effluent flow.

Since the hot liquor tank overflow was clean and hot, continual reuse was the obvious possibility. Unfortunately this proved to be impossible owing to the spasmodic production of this water. As the tank was very large however, it was considered that all its inherent balancing capacity could be utilised if the supply for reuse was taken from the base of the tank rather than from part way down the tank.

Reuse of this water would be preferable in a process that consumed hot water at approximately the same rate as the hot liquor production. The only process in the brewery that utilised this quantity of hot water was the pasteurising machine. However, all of this flow was not hot water since a temperature gradient had to be maintained within the pasteuriser to ensure that bottles were not warmed up or cooled down too rapidly.

It was considered that the hot liquor should be injected directly into the pasteuriser to replace the heating of cold water to 60°C. In addition, the hot water could be blended with the supply of cold water that already existed to give the required temperature profile throughout the pasteuriser. It was estimated that such a system would enable at least half of the excess hot water to be reused each day.

Fermentation Area

The majority of effluent produced in this area of the brewery originated from the CIP systems, the discharges from which contained a high COD load due principally to the high yeast content. With the exception of the initial rinse from pre-fermentation stage gauging vessels, the initial rinses from other tanks—fermentation tanks, storage vessels and yeast recovery vessels—all exceeded 5,000 mg/l COD and together accounted for over 90% of the COD load produced in the fermentation area. Proposals for reducing/treating these discharges were developed as follows.

Possibilities for reducing the pollution load from the gauging vessel CIP effluent were limited as no yeast was present that could be filtered out. However, reuse of the relatively clean final rinse as the initial rinse for the next CIP wash would reduce the effluent flow to drain by a total of 20 m³/d from 6 vessels. It was also noted that the caustic wash from the brewhouse which occurred usually every week was discharged to drain from these gauging vessels every weekend and that this, together with the acid wash from Wort Kettle discharged via a fermentation tank, had a major effect on the combined wastewater pH giving values frequently outside the allowable pH range for discharge to the public sewer of 6–10. Tests showed that if the acid and caustic discharges were run to drain together, the neutralising effect of the acid on the caustic was negligible owing to the different volumes, strengths and buffering capacities involved. Rather than install a localised acid dosing/pH control system to neutralise the predominant caustic load, it was envisaged that closing up the system by providing additional holding tank capacity would be suitable. This could be achieved using a similar arrangement to the existing closed CIP units in order to standardise on equipment; it would reduce effluent flows to drain, raw water costs and also chemical-cleaning costs.

The load produced by the initial rinse of the fermentation tanks was found to be 198 kg COD/d and 120 kg SS/d which could be reduced by at least 75% by passing the rinse through a yeast press. It was considered that the final CIP rinse could also be reused as the initial rinse, reducing effluent flow by 20 m³/d. As referred to above, acid washes from the brewhouse were being discharged from the fermentation tanks; on occasions, these depressed the pH to 3. Containment and recirculation via a new CIP unit were considered to be the most suitable and practicable control measure.

The initial rinse in the storage tank CIP sequence was found to contain 60 kg COD/d and 8 kg SS/d. It was estimated that passing these rinses through a yeast press would reduce overall loads from this source to 18 kg COD/d and 2 kg SS/d. Also, reuse of the final rinse as the initial rinse of the next sequence would reduce effluent flows by 5 m³/d.

Discharges from yeast recovery plant centrifuge cleaning were difficult to arrange at the time of the waste audit and reduction investigations. However, from visual observations the initial rinse clearly contained a significant quantity of yeast and so it was recommended that such wastes should also be passed to a yeast filter press. Similarly, recovery of the final rinse and reuse as a subsequent initial rinse was proposed. It was also suggested that the initial rinses from yeast storage vessels should be filtered through a yeast press. The brewery had already purchased a new yeast press to filter yeast liquors which at the time were stored until press capacity became available. This proposal was expected to reduce storage requirements, allowing a small amount of beer recovery (press filtrate) and elimination of the frequent storage tank overflow.

Therefore, instead of treating each of the fermentation cellar discharges separately which would be uneconomic, the audit team considered that the proposed filter-press installation for the yeast recovery area should be arranged to filter the initial rinses from fermentation tanks, storage vessels and yeast recovery equipment. This would not only prevent the majority of yeast from flowing to drain but would enable its recovery for resale to a food manufacturer. In addition, any other liquor containing yeast that had to be dumped to drain, such as the initial drop from the storage tanks when the yeast storage vessels were full, could be filtered and the yeast and beer recovered. The expected increase in flow to the proposed filter press was estimated to be well within the unit's design capacity.

Treatment Cellar

A number of waste saving options were recommended for this area. The principal measures proposed related to the bottling and kegging areas. The possibilities of utilising the hot liquor tank overflow for the pasteuriser supply have already been highlighted in the brewhouse section above. The audit team felt that the water flowing out of the pasteuriser could be used as an initial rinse in the bottle washer.

The existing bottle washer system used 7 m³/h fresh deionised water. It was proposed that the final sparge pipes should continue

Table 2
Summary of Existing and Proposed Reduced Waste Contributions

Unit Operation	Waste Description	Existing Composition			Recommendation	Predicted Composition		
		m³/d	kg COD/d	kg SS/d		m³/d	kg COD/d	kg SS/d
Lauter Tun	Final run to Drain	40	1000	35	Reuse	0	0	0
Hot Liquor Tank	Overflow	120	—	—	50% reuse as make-up for pasteuriser	60	0	0
Gauging Vessels	CIP wash	20	—	—	Reuse rinsewater	0	0	0
Fermenting Vessels	CIP wash	60	198	120	Reuse and yeast separation	40	50	30
Storage Tanks	CIP wash	15	60	8	Reuse of rinsewaters/pressing of initial rinse	10	18	2
Yeast Storage and recovery	CIP wash	2	15	1	Yeast recovery	2	2	0
Pasteuriser	Process water	75	—	—	Reuse in bottlewasher	0	0	0
Total		332	1273	164		112	70	32

to be supplied with deionised water but that the pasteuriser water be used to supply the remainder and also for continual replenishment of the water in the final rinse tank. Mains water would be provided as a standby supply in the event for any reason that the pasteuriser water ceased.

In the kegging area, dumping of returned beer to drain was occurring periodically giving a very significant rise in COD load during the dumping periods. It was indicated to the company that separate disposal, possibility directly to land, should be seriously considered as often adopted by other breweries.

Summary

Table 2 shows the existing and proposed reduced effluent contributions for the unit operations highlighted.

The predicted reductions on the total effluent discharges were approximately 20% volume, 30% COD load and 15% SS load. This indicated a 25% reduction in trade effluent charges resulting from implementation of the flow/load reduction proposals. This corresponded to reduced average waste quantities per cubic metre of beer produced of 1.6 m³, 6.0 kg COD and 1.8 kg SS.

The audit team appreciated that in addition to savings in trade effluent charges, there would be other cost benefits which were difficult to quantify during the time-frame of the project but which included costs associated with raw water, energy and product.

PRETREATMENT PRIOR TO SEWER DISCHARGE

The strategy of reducing pollution at source reduced the design flows and loads on which to size and cost the effluent pretreatment facilities. Land for the pretreatment plant was limited and therefore only compact processes were investigated. The possible stages considered were:

- screening;
- balancing;
- pH control;
- settlement or flotation with and without chemical addition;
- anaerobic processes;
- aerobic processes including activated sludge, trickling filters and submerged biofilters;
- final settlement; and
- combinations of these.

Capital cost estimates were drawn up following outline design of each option. These were based upon budget price quotations from mechanical and electrical equipment manufacturers and suppliers. Civil engineering costs were estimated by applying actual rates for items currently being constructed as part of ASHACT projects; other items were estimated by taking off quantities for major items, including excavation, concrete, reinforcing steel and formwork and applying published rates.

An economic evaluation of the capital and operating costs of each alternative compared to savings in trade effluent charges including discounted cash flow analyses was undertaken. The operating costs included allowances for chemicals, electricity, wash water, steam, labour and maintenance.

The evaluation identified the best option for the brewery as an on-site pretreatment plant based on pH control, balancing and pure oxygen activated sludge treatment in order to reduce trade effluent charges payable to the water company. This process had the additional attraction of reduced risk of developing filamentous, poorly settling sludges compared with conventional air activated sludge systems treating brewery, or similar wastes, having a high soluble carbohydrate content.

CONCLUSION

The results of the effluent audit and reduction studies were formally presented to the brewery's management in the form of a technical report. The recommendations made were accepted and plans were then made to implement the recommendations. It was recognised that some capital expenditure would be required to implement the proposed effluent reduction programme and that this aspect was best costed by their own engineering staff. However, since the capital sums involved would be relatively small compared to the brewery's capital expenditure budget for the current year, and related to progressive improvements in the brewery production operations, the brewery would be likely to accept the effluent savings proposals on the basis of the significantly reduced trade effluent charge savings alone.

ASHACT have subsequently carried out the detailed process design for the pretreatment plant.

The audit had provided a sound understanding of all principal sources of effluent arising within the brewery. Furthermore, the brewery technologist assigned to assist the waste audit team had benefited greatly from being involved in the step-by-step approach adopted by ASHACT. It was considered that the experience gained by the brewery would enable company staff to take the lead in any future waste audit programme, particularly the assessment of the actual waste reductions achieved following commissioning of the plant modifications and additions proposed.

EVALUATING THE POLLUTION PREVENTION PROGRAM

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MEASURING POLLUTION PREVENTION PROGRESS: A DIFFICULT TASK

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For Presentation at the
83rd Annual Meeting & Exhibition
Pittsburgh, Pennsylvania
June 24-29, 1990

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The Environmental Protection Agency's Pollution Prevention Policy Statement describes a preferred hierarchy of environmental protection which encourages use reduction and preventing the generation of waste by source reduction. If waste generation (including all releases to air, water, and land) cannot be prevented, environmentally sound recycling should be used to manage the wastes. EPA continues to recognize treatment and disposal as useful and necessary management methods when prevention and recycling are not feasible.

There is increasing interest on the part of EPA, States, and industry to measure pollution prevention progress. This paper recounts the evolution of federal pollution prevention reporting requirements. The paper describes problems encountered and changes that have been made by EPA to attempt to solve these problems. Problems that remain to be solved and potential approaches that EPA is considering are also discussed. This paper also describes the experiences of states in implementing these requirements and of industry in trying to provide the information required. Industry and state recommendations for the approach to the reporting requirements are also included.

Before describing pollution prevention data collection efforts, it is necessary to clarify the differences between some of the terms that will be used in this paper: pollution prevention, waste minimization, source reduction and recycling. The term waste minimization was first used in the context of hazardous waste reporting under RCRA. Although EPA's 1986 Report to Congress defined waste minimization to include any source reduction, recycling, or treatment activity that results in reduction in quantity or toxicity of hazardous waste, hazardous waste reporting has focused on source reduction and recycling. The term pollution prevention has been used to extend beyond hazardous waste to include toxic chemical releases and other wastes as well.

Pollution prevention includes use and source reduction, and is intended to emphasize that hazardous waste generation should not be the only focus of an environmental protection program. Chemicals and other substances that are never classified as wastes may be released to all environmental media and in many different forms. Without including releases to all media it is possible to confuse a shift from one media to another through treatment with source reduction activity which reduces total releases to all media.

Source reduction and recycling require different methods to measure progress because they are different in nature. Source reduction reduces generation and release of waste and chemicals prior to any treatment, recycling, or disposal. Recycling takes

waste that has already been generated (or chemicals in the waste) and reuses them for the same or similar purposes. A distinction should also be made between recycling and beneficial use which reuses materials for different purposes such as energy recovery. Beneficial use can be an important way to protect the environment, but is not included as recycling activity. As such it is beyond the scope of this paper.

THE FEDERAL EXPERIENCE IN DEVELOPING POLLUTION PREVENTION DATA COLLECTION REQUIREMENTS

The Hazardous and Solid Waste Amendments of 1984 (HSWA) contained the first federal pollution prevention reporting requirements. Hazardous waste generators were required to certify that they had a program to reduce quantity and toxicity of the hazardous wastes in their manifest for off-site shipments. Treatment, storage, and disposal facilities were required to make a similar certification for hazardous waste generation in permit applications.

Pursuant to HSWA, EPA began to require periodic reporting on waste minimization (source reduction and recycling) in the 1985 Hazardous Waste Biennial Report, with a written description of the waste minimization efforts. However, an assessment of the effect of the activities on quantity and toxicity could not be made because quantity information was not specified. Given the complexity of measuring progress, it would probably not have been possible to specify the information needed at that time.

EPA's first attempt to ask specific questions to quantify pollution prevention and recycling progress was the Hazardous Waste Generator Survey which included waste generation quantity for calendar years 1985 and 1986, quantity recycled in 1986, source reduction and recycling activities implemented prior to and during 1986, and percent change in product production from 1985 to 1986. The survey included production change information because of the recognition that changes in production levels affect waste quantity. Actual production levels were not included in the survey because of confidentiality concerns. The approach of collecting percent change in production rather than actual production levels was similar to the production ratio used by the Chemical Manufacturers Association in a Hazardous Waste Survey of their membership.

Because of concern that there is confusion over the activities that should be reported as source reduction and recycling, the Generator Survey required a written description of the waste minimization activity. This makes it possible to remove treatment, beneficial use, and other activities that are not source reduction and recycling before using quantity information to assess progress. The survey data can then be used to quantify progress of source reduction activities by looking at the actual difference between 1985 and 1986 quantity or by using the production change

information to adjust the actual difference for changes in economic and market conditions.

An EPA study[1] has shown that adjusting for production level is a complex task and that this adjustment is not always appropriate, particularly with multiple product manufacturing, because production does not always influence waste quantity and because other factors can also influence waste quantity. The study found other problems that make it difficult to use Generator Survey data to assess source reduction and recycling progress. Some of the more important findings of that study are summarized below.

> Often metering devices were not available to measure the quantity of waste generated and quantities had to be estimated. Estimates and metering devices may not be very accurate and significant error rates are possible.
>
> Reporting requirements and respondents understanding of them are changing. Some changes in quantity reported are due to changes in the way the wastes were measured or the accounting practices used by the facility rather than actual changes in the quantities generated.
>
> Substantial differences in quantity reported can result from changes in definitions of terms used in the reporting form. This can include changes in reporting criteria, including changes in regulatory definitions and clarifications to instructions.
>
> Effects of source reduction projects may not show up for several years. Thus far, quantitative measures of source reduction only consider changes in the quantity of waste generation which occur during the calendar year in which a source reduction activity is implemented. Source reduction effects may also result in the systematic reduction in waste generation over the life of a production process. It should be possible to understand this effect as we collect information over time.
>
> Using a single measure to summarize source reduction progress does not seem possible. It is necessary to use several measures including actual difference, adjusted difference, and others. In addition to total differences, median difference and percent change should also be used.
>
> The largest facilities unduly influence aggregate quantity measures. It is also important to know the number of facilities that implemented prevention and the number of wastes or chemicals affected.

Even when the different measures are used, actual difference in quanity should be evaluated. In order for prevention to be truly successful, it is necessary to reduce total waste generated

regardless of changes in production and other factors. However, it is not realistic to expect actual reductions in the short term.

The combined effects of these factors limit the types of conclusions that can be made based on data that has been collected. It is possible to 1) identify some of the individual facilities that have made pollution prevention progress, 2) gain and understanding of the number of facilities which implemented pollution prevention activities, and 3) gain and understanding of the number of facilities which showed quantifiable progress (actual or adjusted quantity decrease). It is also possible to make national estimates of the total quantity decrease due to source reduction activities, although the reliability of these estimates is uncertain. However, it is extremely difficult to discuss the policy implications of the data and the estimates based on the data.

The data are sufficient to indicate which facilities and facility categories (industries) show progress. As such they are very useful for identifying types of facilities where progress has and has not been made and developing and targeting technology transfer and other activities. However, they are not sufficient to answer questions such as "Are the facilities making as much progress as they should or which facilities that have not shown progress should be making progress?" With only one year of data it is impossible to describe the potential for prevention activities.

These types of data are most useful for reaching facilities which have not yet implemented prevention - indicating to them that it is possible to reduce wastes and costs of managing them thus increasing profits - and challenging facilities which have implemented prevention to do better. It is difficult to use these data to compare facilities because of the differences in processes and operations at facilities, even when they are in the same industry category. (Advocates of throughput data say that throughput is useful for comparing different facilities; however, throughput data is more burdensome to collect, it is not clear that facility comparisons may be made using throughput data because of their diversity, and the waste per unit product measure may be affected by factors other than prevention just as quantity changes is.)

The survey did not include sufficient information to measure recycling progress because only 1986 quantity recycled was included and there was no information on previous year recycling or on quantity recycled due to activities implemented in the reporting year. The 1989 Biennial Report represents the first time sufficient information has been included to assess recycling progress.

The Generator Survey also did not include sufficient information to assess toxicity reduction. A comprehensive

assessment of toxicity reduction is more difficult and expensive (and not necessarily needed) than assessing quantity reduction because baseline concentration of individual constituents and the change over time would be necessary to assess the degree of reduction in toxicity achieved. Baseline concentration data alone can be very burdensome to report and hazardous waste reporting requirements have not required facilities to submit this data in the past. The Generator Survey asked facilities how source reduction activities affected ("Increase," "Decrease," or "No Change") the toxicity of waste generated, but no attempt was made to quantify this effect.

The 1987 Biennial Report required much of the same information as the Generator Survey, with some important changes. After discussions with industry representatives, respondents were only required to answer the waste minimization section if they had implemented source reduction or recycling activity. There were many improvements in question wording and instructions. The percent change in production was changed to a production index, and respondents were asked to calculate a quantity of waste that was "reduced" using the production index or another more appropriate method. They were required to describe the method they used if they did not adjust the actual quantity change by the production index. This allows assessment of source reduction progress using actual quantity reduction, quantity reduction adjusted for production, or using another method which the facility has found to be more appropriate.

Applying Lessons Learned in the Early Years

For the 1989 Biennial Report, the production index was renamed the activity/production index. This change was made in response to state and industry representatives pointing out that it can be difficult to identify a specific product that is associated with the waste generated. The 1989 Biennial Report also included quantity recycled due to new (rather than ongoing) activities which means that sufficient information should be available for the first time to assess recycling progress. Also new for the 1989 form was the discontinuation of the requirement to provide a written description of the waste minimization activities. This was replaced by a checklist of 40-50 types of projects to choose from. Because there is still confusion over what is and is not waste minimization, the checklist is fairly detailed in order to indicate to respondents the types of activities that should be reported. In addition, the instructions give examples of the types of activities that should not be reported (treatment, beneficial reuse, etc.) as waste minimization.

Developing hazardous waste reporting forms and making these changes over time have placed the Agency in a good position to assess the effect of waste minimization activities on hazardous wastes in the future. However, hazardous waste is not the only universe that must be covered by an assessment of pollution

prevention progress. The Agency is increasingly finding that it is important to encourage prevention of toxic chemical use and release.

Expanding Reporting Beyond the Hazardous Waste Universe

The Agency implemented an optional waste minimization section in the Toxics Release Inventory for calendar year 1987. (The section name was changed to Pollution Prevention: Optional Information on Waste Minimization in 1989.) With toxic chemical reporting, it is very important to 1) define waste as releases to any environmental media 2) include releases to all media since some activities may reduce releases to air while increasing those to water, and 3) require reporting of the quantity of chemical generated in waste prior to treatment and recycling.

The optional pollution prevention section of TRI includes the same type of quantity information - production index and quantity of chemical in waste prior to treatment or otherwise released to air, water, or land for two consecutive years - as the Biennial Report, but does not allow respondents to use an alternate method to calculate the quantity "reduced" or prevented. Although the questions should be modified to include additional information and improve quality of the information submitted, the major weakness of TRI pollution prevention is that it is optional and only about 6% of TRI reports included this information in 1987.

The Agency plans to pursue mandatory pollution prevention reporting for calendar year 1991 which will also incorporate the lessons learned in developing hazardous waste reporting requirements. One approach the Agency is considering is very similar to the approach described in the proposed Waste Reduction Act (H.R. 1457). The types of information that would be added to the TRI Pollution Prevention Section for measuring progress are:

Total quantity of chemical entering recycling and treatment

Quantity of chemical entering recycling due to new activities

Additional information as necessary to indicate the effects of changes in economic conditions and other factors on quantity of chemical generated in waste or otherwise released.

Based on the development of the Biennial Report questions and discussions with industry representatives, one change under consideration is to ask respondents what quantity of chemical would have been generated in waste if source reduction had not been implemented and then subtract this quantity from the current year quantity to estimate the quantity difference due to source reduction. The optional pollution prevention section currently in TRI asks for consecutive year quantity information with the intent being for the Agency to estimate the quantity difference due to

source reduction from this information. (Figure 1 contains examples of the questions under consideration for inclusion in a mandatory Pollution Prevention Section of TRI.)

Coordinating TRI and the Biennial Report

The Agency is also considering ways to coordinate the pollution prevention sections of TRI and the Biennial Report. One way to accomplish this is to devise one set of questions which could be included in both TRI and the Biennial Report (with appropriate skip questions so respondents who receive both forms would only answer the questions once) or could be administered separately (the pollution prevention questions would be removed from the current forms). The Agency has just begun to devise ways to coordinate the forms. One preliminary idea that holds promise is to require reporting based on each pollution prevention project that affects either hazardous wastes or the toxic chemicals in TRI. Respondents would be required to list the TRI chemicals and hazardous wastes that were affected by each project and provide quantity change (both increases and decreases) information first for wastes and then for chemicals. Figure 2 contains example questions that might be asked using this format.

Using this approach, respondents would only describe a pollution prevention project one time and would provide information to quantify the effects of the project on all chemicals or hazardous wastes affected in the same form. In addition to streamlining the reporting process, this approach seems to provide additional information and facilitate analyses that cannot be made using the separate forms. This approach can be used to begin assessment of changes in toxicity of hazardous wastes. Although the chemical quantity information would be for the entire facility and not for each waste, it would still be possible to see that the project that affected waste quantity also affected chemical quantities. There is currently no way to quantify effects on toxicity.

This approach would also allow assessment of activities that substitute one chemical or waste constituent for others that presumeably pose less threat to the environment. Since both increases and decreases of any wastes and chemicals affected by a project would be reported it will be possible to begin to understand the overall effects a project that increased some and decreased others.

The improvements in hazardous waste reporting and the use of either of these approaches to TRI reporting should provide sufficient information to assess pollution prevention progress. However, many of the problems associated with collecting and analyzing data will continue to make it necessary to look at many different measures to make that assessment.

The remainder of this paper describes the experience of states in implementing implementing pollution prevention reporting requirements and of industry in providing information pursuant to pollution prevention reporting requirements.

MINNESOTA'S EXPERIENCE IN COLLECTING WASTE MINIMIZATION BIENNIAL REPORT DATA

Waste minimization data was collected from large quantity generators in Minnesota in early 1988 for the years 1986 and 1987. This section provides an account of the data collection, compilation, and validation in Minnesota and the difficulties that were encountered. Many of the reporting errors experienced by Minnesota were similar to those experienced as part of federal reporting efforts.

Data Collection

In late 1987, the Minnesota Pollution Control Agency (MPCA) and Minnesota Technical Assistance Program (MnTAP) began to work together to prepare for the waste minimization biennial report data collection. The MPCA annual report forms for waste generators were used in place of the U.S. EPA biennial report forms. However, MPCA agreed to use the U.S. EPA waste minimization forms with minor modifications to clarify format and instructions.

In January of 1988, the modified EPA forms, with instructions and codebooks, were sent to 350 large quantity generators in the State of Minnesota. This mailing effort was conducted through a joint MPCA, MnTAP, and Twin Cities metropolitan county effort. In the Twin Cities metro area, the seven metro counties have the authority to enforce RCRA. By April 1, 1988, the 350 forms (100% return) had been returned to MPCA. Even though it was not a requirement, approximately 5,000 forms were sent to small quantity generators in Minnesota in an abbreviated, qualitative format which did not include request for quantitative results. About 3,300 of these forms were returned (66% return).

Data Compilation

With software developed by EPA and its contractors, and the applications software (PC Focus) borrowed from EPA Region V, MnTAP hired a student through the University of Minnesota to enter the data into the computer. Data entry for 350 large generator forms took the equivalent of six weeks of a student's time. No data validation was conducted prior to data entry. Many computer, data, and software problems had to be worked out during that time period.

Once all the data was entered, data summaries were printed out by SIC code and waste category. The data had to be manually

converted to the same unit of measure (pounds was used as the common unit) within each SIC code and waste category number, because the computer program would not make those conversions. Rough calculations were made on percent prevention and recycling based on differences in 1986 and 1987 waste generation reported, not taking into account production changes.

Data Validation

Due to concerns about the way data was entered on the forms, a data validation exercise was conducted for the top 30 largest generating facilities that reported. New figures were calculated for the amount of waste prevented and recycled considering production changes. These calculated figures were compared with reported figures for waste prevention, and generally did not compare favorably (see Table _____). This suggested the numbers reported by large quantity generators are not representative of actual prevention achieved. Thus, it was concluded that reporting errors are significant, and the manner in which prevention projects were identified was not necessarily correct. For example, a number of projects reported to have achieved significant reductions were actually installations of pretreatment systems or were sludge drying projects. This problem was noted earlier in this paper, and was one commonly experienced in early reporting efforts.

Concerns About the Reporting Exercise and Sources of Error

Use of the data from the first reporting should be considered in light of its limitations. The potential for inaccurate data is high due to at least two factors identified during the reporting process:

- o generator uncertainties with regard to the definition of waste recycling and waste prevention, resulting in the inclusion of treatment and incineration as recycling and prevention activities

- o inaccuracies (including not reporting or not knowing) in entering a number for production ratio which would give an indication of waste produced as a result of market factors. As a result, waste reported recycled or prevented is based on the incorrect assumption that production stayed the same from 1986 to 1987

Cost of Waste Minimization Data Collection

Documented costs for the 1988 Minnesota data collection, compilation and validation exercise totalled approximately $15,000 for copying, mailing, supplies, computer equipment, hiring data entry personnel, etc. This does not include technical staff time spent on the project from MPCA, MnTAP, and volunteer assistance received from 3M.

State regulatory agencies typically do not have the staff or financial resources to allocate to an effort as comprehensive as collecting meaningful waste minimization data. A large incentive to the collection of accurate data would be the provision of funds from EPA to the states to provide resources for software, computers, staff, administrative, mailing, copying and other costs.

INDUSTRY VIEW ON HOW TO COLLECT DATA

The following discussion is based on the experience companies have had in submitting agency requested waste minimization progress data on agency developed forms. This includes the 1986 Generator Survey, and the waste minimization RCRA Biennial Report forms issued by the USEPA for the data years 1987 and 1989. Also explained is why more than 90% of the companies did not optionally report waste minimization data for the Sara 313 Form R under Part B.

Background:

The National Association of Manufacturers coordinated industry efforts to provide input on how to collect waste minimization data to USEPA Office of Solid Waste and the Office of Toxic Substances. Included were The Business Roundtable Environment Task Force Staff Committee, and the Chemical Manufacturer's Association.

Industry input was also provided through the National Governor's Association Advisory Council on the RCRA Annual/Biennial Report. The council consisted of invited environmental representatives of corporations, states, USEPA and public interest groups.

One positive result of the industry efforts was the agency agreement to use "exception" reporting for waste minimization. Only those companies who had a waste minimization project or activity in the reporting year, were required to submit data to show the progress made.
This "minimized" the number of forms USEPA had to review to compile data on waste minimization progress.

Another positive result from the discussions was related to the forms themselves. Unfortunately, the format used initially for data collection was seriously flawed for multi-product manufacturing companies, with combined waste streams. The format was changed for the 1989 reporting year for the RCRA Biennial Report. However, the form needs to be further improved. It was not clearly stated that multi-product manufacturing companies with combined waste streams had the option to report the results of the waste minimization projects.

How to Improve Data Collection for Waste Minimization:

What follows is a discussion of two important suggested ways in which the process for collecting waste minimization data can be improved by the agency:

Suggestion 1. Provide Option to Report Results of Generation Prevention Projects
Suggestion 2. Make the Forms Self Explanatory

Suggestion 1. Need to provide option

The agency agrees on the need for providing this option. However this option has not been clearly stated on the forms or in the instructions.

The problem with quantifying prevention is that there is a big practical difference in the ability to quantify prevention in generation of wastes from "a multi-product facility making many products and combining its waste streams", compared with "a single product facility which is dedicated to making only one product."

Most of the 30,000 large quantity generators and more that 100,000 small quantity generators have multi-product operations with combined waste streams.

For single product facilities, the amount prevented from being generated can be estimated using the overall balance approach, by taking the difference in total waste amounts generated each year for a waste code, and adjusting for average production.

However, this overall balance procedure is seriously flawed for multi-product manufacturing operations with combined waste streams.(1,2) The reason is that normal production variation from year to year of the different products generating different types and amounts of waste, will mask any waste minimization activities and skew the results in an unpredictable manner. Also adding to the uncertainty is the change from year to year, in the mix of products being made; products dropped and new products added, each with different types and amounts of waste.

A detailed explanation is provided in references 1 and 2 of the complexity of multi-product facilities with examples showing why the overall balance procedure for a "single product facility" is not applicable,

It is not practical to measure the individual waste generated by every single product for these multi-product facilities. This is due the complexity of operations. Any attempt to do so would disrupt the manufacturing operation, without any useful, operative benefit.

COMPLEXITY OF MULTI-PRODUCT MANUFACTURING FACILITIES.

A typical coating line used for making pressure sensitive tape is shown in Figure 3. There could be as many as 20 of these individual coating process lines at a multi-product tape manufacturing

facility. The wastes from all 20 process lines are combined, and reported that way.

Variability of coating line operations and waste generated

The number of different products made at a facility during the year can vary from 53 to 600 products. The number of coatings required to make a single product can vary from 2 to 10 coatings. Each coating can contain various mixed solvents and several different raw materials.

Product runs can vary from 45 minutes to 2 hours, or as long as two weeks. Some products will require the coatings be applied at several different coating lines.

The multi-media wastes normally generated include USEPA Waste Code F 003, pumpable solvent wastes and non-pumpable solvent contaminated rags, gloves, filters, etc. from cleanup between product runs, air emissions from the stacks, fugitive emissions, waste water from cleanup, and off-spec raw material or product waste.

The solvent waste generated is usually collected in 55 gallon drums. It is not possible to easily measure several gallons of waste from a short run, or one third of a barrel of waste from a longer run. This is one reason the wastes are aggregated. Further, the aggregated amounts can include wastes from other coating lines in the facility.

Example of masking of waste minimization results
In Table 2 is one simplified example from the references which shows a waste minimization project which prevented the generation of 7.5 tons/year of waste for one product. The effects of the project have been masked by changes in production units of the other products.

Referring to Table 2, it is important to note that the facility only reports the aggregated totals of waste to the agency. It does not have the "tons of waste generated" for each individual product. It can be seen in Table 2, that even though the efficiency was improved and the "tons waste per unit of product" for Product A was reduced by waste minimization, it did not show up in the aggregated amount which stayed the same at .30 "tons of waste per unit of product". The results of the waste minimization project were masked by the totals of combined wastes which are reported to the agency.

Examples of other types of multi-product manufacturing operations with similar problems for measuring progress in generation prevention include the manufacture of adhesives, coatings and sealants, electroplating, the manufacture of specialty chemicals, and certain refinery operations.

Suggestion 2. Make the Forms Self Explanatory

Self explanatory forms without detailed instructions would give the agency the best shot at collecting good data. The best way to insure getting good data is to "Keep it Simple".

Unfortunately, a decision was made on the waste minimization portion of the biennial report to ask for detailed data and "force" the plant persons who had to fill out the forms to "read the instructions". It won't work, and here's why:

Most persons are intimidated by detailed instructions and will not be able to understand them.

Consider that:

a. Based on a review of the forms in Minnesota and other states, half of the persons filling out the forms are non-technical, and are intimidated by detailed instructions.

b. Those persons who are technical cannot find time to read detailed complex forms and instructions. This is because of the overwhelming burden of all USEPA regulations, and trying to keep the facility running. These persons will make a conscientious effort to complete the forms, based on time available to do it and still keep the facility running.

An example of industry's one page, suggested self-explanatory form is shown in Figure 4. Using a form like this would substantially reduce the burden on industry to provide data, and reduce the burden on the agency to validate and compile the data. It would substantially reduce agency expenditures to prepare the forms and instructions. It would also reduce agency expenditures on consultants to assist companies in understanding the instructions, and in analyzing the data.

It would show where waste minimization is taking place, the type and how much. For support of the agency's pollution prevention program, the agency could then go back and obtain additional detailed information, if desired, from those companies who reported substantial waste minimization progress.

An example of how the data can be collated to show trends in waste minimization progress, is shown in Figure 5. The data could be compiled by waste codes, or for various industry categories by SIC Codes, or by states, etc. to show trends.

In Figure 5 the reported "amount generated" is for all of the combined waste streams for a given waste code. Note however that the "amount prevented" is based on the results of the waste minimization project which could affect only one or two waste streams.

For example, the "amount generated" could be based on 30 combined waste streams for the waste code being reported for the facility. However, the "amount prevented" or "amount recycled" is based on only the one or two waste streams affected by the waste minimization project.

DATA COLLECTED TO DATE BY USEPA

1986 Generator Survey: In the 1986 Generator Survey, the agency asked for only generation rates for the years 1985 and 1986 and the production ratio, if available. As explained above and shown in the reported Minnesota experience, this data cannot be used to calculate waste minimization progress for 1986. Production variation and the change in product mix from 1985 to 1986 will skew the results in an unpredictable manner and mask any waste minimization progress.

SARA 313 Optional Waste Minimization Reporting: Companies were given the option to report waste minimization progress on specific chemicals in the same format as the 1986 Generator Survey. Companies do not collect wastes by specific chemical, but rather by waste streams which include many chemicals. Attempting to analyze and compile the amounts of each SARA 313 chemical in every waste stream, would be a tremendous task at multi-product facilities. The data, once obtained, would be of little value in showing waste minimization progress at the facility. It is for this reason that more than 90% of the companies did not complete Part 8 of Form R, on optional waste minimization reporting.

However, companies are looking at the practicability of collecting data on the SARA 313 chemicals in the waste streams of the successful waste minimization projects at facilities, and optionally reporting these project results.

RCRA Biennial Reports - Waste Minimization Portion

Unfortunately, the waste minimization report forms did not clearly show companies had an option to report the results of waste minimization projects, if reporting yearly generation rates and a production ratio was not relevant to show waste minimization progress. For this reason, validating and evaluating waste minimization progress from the biennial reports for the data years 1987, and 1989, will be a difficult, if not impossible, task.

RECOMMENDATIONS
An option should be provided more clearly on the data collection forms to allow companies to report the results of waste minimization projects at each facility.

This would allow the agency and companies to track and report waste minimization progress similar to the way 3M has monitored the

ults of the multi-media Pollution Prevention Program (3P) since was initiated in 1975.

h 3P project submittal form includes a description of the ject and an estimate of the amount of pollutants prevented from ng generated or released the first year. Also included is the st year cost savings resulting from the project. A typical ort of eight 3P projects is shown in Table 3 (3)

vision could be made on the existing RCRA Waste Minimization ort forms, to report hazardous waste minimization results in s manner from multi-product manufacturing facilities when licable.

CONCLUSIONS

For multi-product manufacturing operations, the USEPA should e clearly give companies the option to report the results of te minimization projects at the facilities. This should be done both the RCRA Biennial Report and for SARA Title III Form R ional Part B.

In addition, the agency should seriously consider adopting icy to make the forms self-explanatory, with minimal tructions, as in the example shown.

s may mean collecting less detailed data, but that would be good both industry and the agency. Especially since the USEPA today s not appear to have the resources to analyze all of the data has collected, nor do the state agencies.

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Table 1. A Sample of Reported Values from the 1988 Minnesota Waste Minimization Data Collection Effort

Company	(1) 1986 Generated (lbs.) Actual Reported	(2) 1987 Generated (lbs.) Actual Reported	(3) Prod. Ratio (PR)	(4) 1987 Expected Generated Adjusted (per production ratio) Col 2 x Col 3	(5) 1987 Calculated Waste Prevented Col 4-Col 2	(6) 1987 Waste Prev. Rep. by Company
Company A (correctly calculated)	188,080	141,060	1.0	188,080	47,020	47,020
Company B (reported exceeds calculated)	245,980	130,340	.88	216,462	86,122	115,640
Company C (calculated exceeds reported)	806,856	1,107,208	1.4	1,129,598	22,390	1,400

NOTE TO EDITORS

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TABLE 2.

MULTI PRODUCT OPERATION – COMBINED WASTE STREAMS

CASE I – WITH WASTE MINIMIZATION PROJECT

SIC CODE ____ WASTE CODE ____

	PRODUCT	UNITS OF PRODUCT	PROD RATIO 1987/1986	TONS WASTE GENERATED ADJUSTED FOR PRODUCTION	TONS WASTE GENERATED ACTUAL	TONS WASTE PREVENTED	TONS WASTE PER UNIT OF PRODUCT
1986	A	35	NA	NA	15	NA	.43
	B	50	NA	NA	10	NA	.20
	C	15	NA	NA	5	NA	.33
	AGGREGATED TOTAL	100	NA	NA	30		.30
1987	A	70	2		22 1/2		.33
	B	25	1/2		5		.20
	C	30	2		10		.33
	AGGREGATED TOTAL	125	1.25 AUG	37.5 CALCULATED	37.5	APPARENT INCREASE 7.5 TONS	.30

90-41.3

TRACKING WASTE MINIMIZATION PROJECTS

DATA SUMMARY

TABLE 3.

PROJECT NAME	DATE	PLANT	POLLUTANTS PREVENTED (TONS/YR) AIR	WATER	W/W	SOLID	HAZ.
REFORMULATION	1987	A				1	1
RADIATION POLYMER.	1987	B	3000				
VAPOR DEG/ SOLV. SUB.	1987	C	45				
FREON REPLACE/ IN CANS	1987	D	313			430	430
SPRAY DRIED/ LEAD ELIM.	1988	E	430	3.5			
ALTERN. EMULSIFIER	1988	F				643	327
HIGH SOLID ADHESIVE	1988	G	332				
ZINC OXIDE REDUC.	1988	H				70	70

90-41.3

TRACKING WASTE MINIMIZATION PROJECTS

DATA SUMMARY
TABLE 3. (Continued)

90-41.3

PROJECT NAME	DATE	PLANT	FIRST YEAR SAVINGS – ($/YR) CAPITAL COST AVOIDED	OPER. COST AVOIDED	OTHER	ENERGY SAVINGS	TOTAL
REFORMULATION	1987	A			330,000		330,000
RADIATION POLYMER.	1987	B	1,000,000				1,000,000
VAPOR DEG/ SOLV. SUB.	1987	C	50,000	23,800			74,000
FREON REPLACE/ IN CANS	1987	D				236,000	236,000
SPRAY DRIED/ LEAD ELIM.	1988	E					200,000
ALTERN. EMULSIFIER	1988	F	5,000	440,000		12,000	457,000
HIGH SOLID ADHESIVE	1988	G		780,000		650	780,700
ZINC OXIDE REDUC.	1988	H	500,000	625,000			1,125,000

Figure 1: Potential Approach to Pollution Prevention Reporting in the 1991 Toxic Release Inventory 90-41.3

I. Quantity of Chemical in Wastes (Releases to Air, Water, and Land)

1. Total Quantity of chemical generated in wastes prior to treatment, recycling, or disposal — 1991 ☐☐☐☐☐☐☐ 1990 ☐☐☐☐☐☐☐

2. Total Quantity of chemical in waste entering treatment on-site in 1991 ☐☐☐☐☐☐☐

3. Total Quantity of Chemical Entering Recycling in 1991 (Do Not Include Closed-Loop (Direct) Recycling Here) — On-Site ☐☐☐☐☐☐☐ Off-Site ☐☐☐☐☐☐☐

4. Total Quantity of Chemical Entering Recycling in 1990 (Do Not Include Closed-Loop (Direct) Recycling Here) — On-Site ☐☐☐☐☐☐☐ Off-Site ☐☐☐☐☐☐☐

6. Percent reduction goals for generation of this chemical in waste for the next two years. Use 1991 as the Base Year for calculations. — 1992 ☐☐☐ 1993 ☐☐☐

II. Pollution Prevention Activities (Preventing Generation of Chemical in Waste, & Recycling)

Indicate actions taken to reduce the amount of chemical in wastes (air emissions, water discharges, or land releases prior to recycling, treatment, or disposal) Include Source reduction and recycling.

☐ Check here if no new pollution prevention activities were implemented in 1991. There is no need to complete the rest of the questions on this form.

6a Description of Source Reduction Activity ☐☐ ☐☐ ☐☐ ☐☐ — 6b Reason for Action ☐☐

7a Description of Recycling Activity ☐☐ ☐☐ — 7b Reason for Action ☐☐

Source Reduction Progress (Prevention of Generation of Chemical in Waste)

8. Quantity of Chemical in Wastes Affected By Project (If different from total quantity of chemical in wastes reported in Question 1) — 1991 ☐☐☐☐☐☐☐ 1990 ☐☐☐☐☐☐☐

9. Quantity of Chemical that would have been generated in wastes in 1991 without Source Reduction activities. There are several different ways that this quantity can be calculated. Choose the one that is most appropriate for this project and the chemicals it affects. ☐☐☐☐☐☐☐

Method Used to Calculate Quantity (Check box to indicate method used)

☐ Used 1990 Quantity as estimate of 1991 Quantity without Source Reduction (Use this if Production Does Not Significantly Affect Quantity of Chemical in Waste)

☐ Used Activity/Production Index to adjust for level of business activity or production. See instructions

Report Activity/Production Index Here ☐.☐

☐ Used Another Method (Describe) _____

10. Estimated Change in Quantity Due to Source Reduction (Subtract 8 (1991) from 9) This is placed on the form so you can check its reasonableness and use the information in facility planning. ☐☐☐☐☐☐☐

Recycling Progress

11. Of the Amount Reported in 3 Above, Total Quantity of Chemical Entering Recycling in 1991 Due to New Activities — On-Site ☐☐☐☐☐☐☐ Off-Site ☐☐☐☐☐☐☐

Figure 2: Potential Approach to Pollution Prevention Project Reporting

Project Description

Make a copy of this form for each new pollution prevention project. Indicate actions taken to reduce the amount of chemical in wastes (air emissions, water discharges, or land releases prior to recycling, treatment, or disposal.) Include Source reduction and recycling.

Description of Project ☐☐☐☐ Reason(s) for Action ☐☐☐

☐ Check here if no new pollution prevention projects were implemented in 1991. Do not complete the remainder of the form.

List TRI Chemicals and Hazardous Wastes Affected by the Project

_____ _____ _____ _____ _____ _____

Effect of Project on Hazardous Wastes

A	B	C	D	E	F	G	H	I
RCRA Waste Code	Quantity of this waste that is Affected by this Project: 1991 Quantity	1990 Quantity	Quantity that would have been generated without this project	Method (See Below)	Activity/ Production Index	Difference (D - 1991)	New Recycling: On-Site	Off-Site
☐☐☐☐	☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐	☐	☐.☐	☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐
☐☐☐☐	☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐			☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐
☐☐☐☐	☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐			☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐

Effect of Project on TRI Chemcials

A	B	C	D	E	F	G	H	I
Chemical Name	Quantity of this chemical in waste that is Affected by this Project: 1991 Quantity	1990 Quantity	Quantity that would have been generated without this project	Method (See Below)	Activity/ Production Index	Difference (D - 1991)	New Recycling: On-Site	Off-Site
_____	☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐	☐	☐.☐	☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐
_____	☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐			☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐
_____	☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐			☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐	☐☐☐☐☐☐☐☐

Method Used to Calculate Quantity (Check box to indicate method used)

A. Used 1990 Quantity as estimate of 1991 Quantity without Source Reduction (Use this if Production Does Not Affect Quantity

B. Used Activity/Production Index to adjust for level of business activity or production. See instructions

C. Used Another Method (Describe) _____

_____

FIGURE 3. TYPICAL COATING LINE
PRESSURE SENSITIVE TAPE

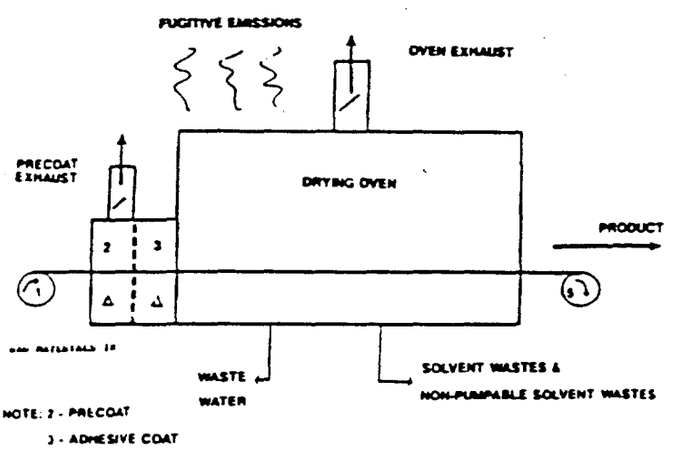


FIGURE 4. INDUSTRIES' ONE PAGE, SELF-EXPLANATORY PROPOSED FORM
MAKE A COPY OF THIS FORM FOR EACH NEW WASTE MINIMIZATION PROJECT

BEFORE COPYING THIS FORM, ATTACH SITE IDENTIFICATION LABEL OR ENTER:

SITE NAME _____

EPA ID NO

U.S. ENVIRONMENTAL PROTECTION AGENCY

1988 or 1989

FORM WM

WASTE MINIMIZATION REPORT FOR ☐ 1988 ☐ 1989

WHO MUST COMPLETE THIS FORM? This form must be completed by large generators that completed a new waste minimization activity, or project in 1988 or 1989.

Waste minimization means:

(1) Any new activity which prevents generation of Hazardous Waste.

(2) Any new recycling of hazardous waste - onsite or offsite.

INSTRUCTIONS:

Enter "DK" for "don't know" or "not available."

Sec. I

A EPA hazardous waste code

B Prevented
- ☐ Good Practice
- ☐ Inventory Control
- ☐ Spill Leak Prevention
- ☐ Raw Material Substitution
- ☐ Process Modification
- ☐ Product Modification
- ☐ Direct Recycle

C Description of product or service

D SIC Code

E Waste form code
- ☐ Gas
- ☐ Liquid
- ☐ Solid
- ☐ Not known

SARA 313 — TRI Constituents
- ☐ Not required for facility
- ☐ Required but none on list
- ☐ Req'd & SARA 313 chemicals are in waste
- ☐ Don't know

H Source description:
- ☐ Cleaning and degreasing
- ☐ Surface preparation
- ☐ Other than surface preparation
- ☐ One time event
- ☐ Treatment

I Origin
- ☐ Generated on site
- ☐ Rec'd from off site
- ☐ Residue from onsite Treat or Recover

Sec II

Results of project or activity
Show Quantity of Waste Prevented or Newly Recycled
Complete either Item 1 or Item 2 - Describe in Section III

PROJECT ☐ Prevented Generation or ☐ Newly recycled

Item 1. Single Uncombined Waste Stream - Single Product Manufacturing

A. 1987 Quantity Generated _____ ☐ Tons ☐ Pounds

B 1988 Quantity Generated _____ ☐ Gals. _____ lb/gal

C Production Rate _____

D Calculate Quantity Prevented or Newly Recycled in year reported

A = C - B = _____ Prevented ☐ Onsite ☐ Offsite ☐ Newly Recycled ☐ Onsite ☐ Offsite ☐

Item 2 Combined Waste Streams - Multi Product Manufacturing

A Estimate Quantity Prevented in year reported _____ ☐ Tons ☐ Pounds

Explain Estimate in Section III

B. Quantity Newly Recycled in year reported _____ ☐ Gals. _____ lb/gal

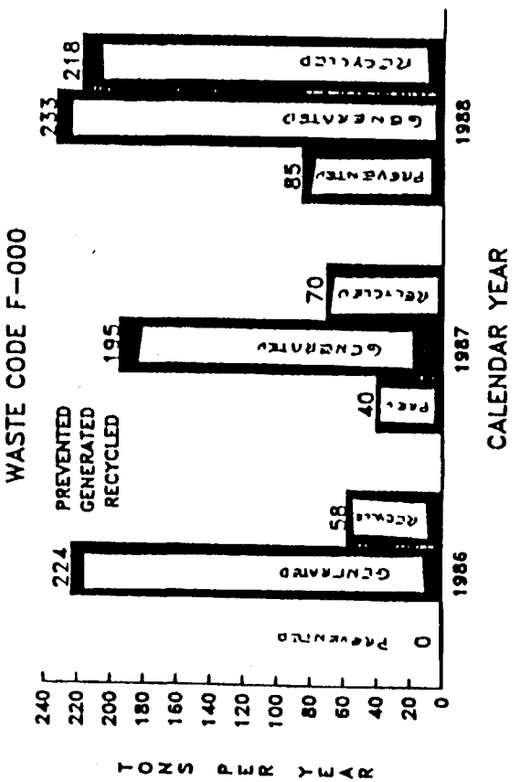
Sec III

A Narrative description of waste minimization project or activity and results achieved.

FIGURE 5. SUMMARY WASTE MINIMIZATION TRENDS

SICO CODE 000 LARGE QUANITY GENERATOR COMPANY
WASTE CODE F-000

EXAMPLE



AUDIT FORMS

Firm _____	Pollution Prevention Assessment Worksheets	Prepared By _____
Site _____		Checked By _____
Date _____	Proj. No. _____	Sheet ___ of ___ Page ___ of ___

WORKSHEET
2

SITE DESCRIPTION

Firm: _____

Plant: _____

Department: _____

Area: _____

Street Address: _____

City: _____

State/Zip Code: _____

Telephone: ( ) _____

Major Products: _____

_____

SIC Codes: _____

EPA Generator Number: _____

Major Unit: _____

Product or Service: _____

Operations: _____

_____

_____

_____

_____

_____

Facilities/Equipment Age: _____

_____

_____

_____

Firm _____	Pollution Prevention Assessment Worksheets	Prepared By _____
Site _____		Checked By _____
Date _____	Proj. No. _____	Sheet ___ of ___ Page ___ of ___

WORKSHEET
3

PROCESS INFORMATION

Process Unit/Operation: _____

Operation Type: ☐ Continuous ☐ Discrete ☐ Batch or Semi-Batch ☐ Other _____

Document	Status					
	Complete? (Y/N)	Current? (Y/N)	Last Revision	Used in this Report (Y/N)	Document Number	Location
Process Flow Diagram						
Material/Energy Balance						
Design						
Operating						
Flow/Amount Measurements						
Stream						
Analyses/Assays						
Stream						
Process Description						
Operating Manuals						
Equipment List						
Equipment Specifications						
Piping and Instrument Diagrams						
Plot and Elevation Plan(s)						
Work Flow Diagrams						
Hazardous Waste Manifests						
Emission Inventories						
Annual/Biennial Reports						
Environmental Audit Reports						
Permit/Permit Applications						
Batch Sheet(s)						
Materials Application Diagrams						
Product Composition Sheets						
Material Safety Data Sheets						
Inventory Records						
Operator Logs						
Production Schedules						

Firm _____	Pollution Prevention Assessment Worksheets	Prepared By _____
Site _____		Checked By _____
Date _____	Proj. No. _____	Sheet ___ of ___ Page ___ of ___

WORKSHEET
4

INPUT MATERIALS SUMMARY

Attribute	Description		
	Stream No. ____	Stream No. ____	Stream No. ____
Name/ID			
Source/Supplier			
Component/Attribute of Concern			
Annual Consumption Rate			
Overall			
Component(s) of Concern			
Purchase Price, $ per _____			
Overall Annual Cost			
Delivery Mode[1]			
Shipping Container Size & Type[2]			
Storage Mode[3]			
Transfer Mode[4]			
Empty Container Disposal Management[5]			
Shelf Life			
Supplier Would			
— accept expired material? (Y/N)			
— accept shipping containers? (Y/N)			
— revise expiration date? (Y/N)			
Acceptable Substitute(s), if any			
Alternate Supplier(s)			

Notes:
1. e.g., pipeline, tank car, 100 bbl tank truck, truck, etc.
2. e.g., 55 gal drum 100 lb paper bag, tank, etc.
3. e.g., outdoor, warehouse, underground, aboveground, etc.
4. e.g., pump, forklift, pneumatic transport, conveyor, etc.
5. e.g., crush and landfill, clean and recycle, return to supplier, etc.

Firm _____	Pollution Prevention Assessment Worksheets	Prepared By _____
Site _____		Checked By _____
Date _____	Proj. No. _____	Sheet ___ of ___ Page ___ of ___

WORKSHEET
5

PRODUCTS SUMMARY

Attribute	Description		
	Stream No. ____	Stream No. ____	Stream No. ____
Name/ID			
Component/Attribute of Concern			
Annual Production Rate			
Overall			
Component(s) of Concern			
Annual Revenues, $ _____			
Shipping Mode			
Shipping Container Size & Type			
Onsite Storage Mode			
Containers Returnable (Y/N)			
Shelf Life			
Rework Possible (Y/N)			
Customer Would			
— relax specification (Y/N)			
— accept larger containers (Y/N)			

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Firm _____	Pollution Prevention Assessment Worksheets	Prepared By _____
Site _____		Checked By _____
Date _____	Proj. No. _____	Sheet ___ of ___ Page ___ of ___

WORKSHEET
6

WASTE STREAM SUMMARY

Attribute	Description		
	Stream No. ____	Stream No. ____	Stream No. ____
Waste ID/Name:			
Source/Origin			
Component or Property of Concern			
Annual Generation Rate (units _____)			
Overall			
Component(s) of Concern			
Cost of Disposal			
Unit Cost ($ per: _____)			
Overall (per year)			
Method of Management[1]			

Priority Rating Criteria[2]	Relative Wt. (W)	Rating (R)	R x W	Rating (R)	R x W	Rating (R)	R x W
Regulatory Compliance							
Treatment/Disposal Cost							
Potential Liability							
Waste Quantity Generated							
Waste Hazard							
Safety Hazard							
Minimization Potential							
Potential to Remove Bottleneck							
Potential By-product Recovery							
Sum of Priority Rating Scores		Σ(RxW)		Σ(RxW)		Σ(RxW)	
Priority Rank							

Notes:
1. For example, sanitary landfill, hazardous waste landfill, on-site recycle, incineration, combustion with heat recovery, distillation, dewatering, etc.
2. Rate each stream in each category on a scale from 0 (none) to 10 (high).

Firm _____	Pollution Prevention Assessment Worksheets	Prepared By _____
Site _____		Checked By _____
Date _____	Proj. No. _____	Sheet ___ of ___ Page ___ of ___

WORKSHEET
7

OPTION GENERATION

Meeting format (e.g., brainstorming, nominal group technique) _____

Meeting Coordinator _____

Meeting Participants _____

List Suggestion Options	Rationale/Remarks on Option

Firm _____	Pollution Prevention Assessment Worksheets	Prepared By _____
Site _____		Checked By _____
Date _____	Proj. No. _____	Sheet ___ of ___ Page ___ of ___

WORKSHEET
8

OPTION DESCRIPTION

Option Name: _____

Briefly describe the option: _____

_____

_____

_____

_____

_____

_____

_____

Waste Stream(s) Affected: _____

_____

Input Material(s) Affected: _____

_____

Product(s) Affected: _____

_____

Indicate Type:

☐ Source Reduction
- ____ Equipment-Related Change
- ____ Personnel/Procedure-Related Change
- ____ Materials-Related Change

☐ Recycling/Reuse
- ____ Onsite
- ____ Offsite
- ____ Material reused for original purpose
- ____ Material used for a lower-quality purpose
- ____ Material sold

Originally proposed by: _____ Date: _____

Reviewed by: _____ Date: _____

Approved for study? _____ yes _____ no By: _____

Reason for Acceptance or Rejection _____

Firm _____	Pollution Prevention Assessment Worksheets	Prepared By _____
Site _____		Checked By _____
Date _____	Proj. No. _____	Sheet ___ of ___ Page ___ of ___

WORKSHEET
9

PROFITABILITY

Capital Costs

Purchased Equipment _____

Materials _____

Installation _____

Utility Connections _____

Engineering _____

Start-up and Training _____

Other Capital Costs _____

Total Capital Costs _____

Incremental Annual Operating Costs

Change in Disposal Costs _____

Change in Raw Material Costs _____

Change in Other Costs _____

Annual Net Operating Cost Savings _____

$$\text{Payback Period (in years)} = \frac{\text{Total Capital Costs}}{\text{Annual Net Operating Cost Savings}} = _____$$

Firm ABC CORP Site LOS ANGELES Date MARCH, 1991	Pollution Prevention Assessment Worksheets Proj. No. 1	Prepared By DGL Checked By DEP Sheet 1 of 1 Page 1 of 18

WORKSHEET
1

WASTE SOURCES

Waste Source: Material Handling	Significance at Plant		
	Low	Medium	High
Off-spec materials	X		
Obsolete raw materials	X		
Obsolete products		X	
Spills and leaks (liquids)		X	
Spills (powders)	X		
Empty container cleaning	X		
Container disposal (metal)	X		
Container disposal (paper, plastic)		X	
Pipeline/tank drainage			X
Laboratory wastes		X	
Evaporative losses	X		
Other			
Waste Source: Process Operations			
Tank cleaning		X	
Container cleaning	X		
Blender cleaning	X		
Process equipment cleaning		X	

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Firm ABC CORP Site LOS ANGELES Date MARCH, 1991	Pollution Prevention Assessment Worksheets Proj. No. 1	Prepared By DGL Checked By PED Sheet 1 of 1 Page 2 of 18

WORKSHEET
2a

WASTE MINIMIZATION: Material Handling

A. GENERAL HANDLING TECHNIQUES

Are all raw materials tested for quality before being accepted from suppliers? ☑ Yes ☐ No

Describe safeguards to prevent the use of materials that may generate off-spec product: REQUIRE VENDOR TO PROVIDE CERTIFICATE OF ANALYSIS BEFORE USE.

Is obsolete raw material returned to the supplier? ☐ Yes ☑ No

Is inventory used in first-in first-out order? ☑ Yes ☐ No

Is the inventory system computerized? ☐ Yes ☑ No

Does the current inventory control system adequately prevent waste generation? ☑ Yes ☐ No

What information does the system track? PRODUCT/MATERIAL NAME, LOT NUMBER, CONTROL NUMBER, DATE RECEIVED, EXPIRATION DATE.

Is there a formal personnel training program on raw material handling, spill prevention, proper storage techniques, and waste handling procedures? ☐ Yes ☑ No

Does the program include information on the safe handling of the types of drums, containers and packages received? ☐ Yes ☐ No

How often is training given and by whom? N/A

Is dust generated in the storage area during the handling of raw materials? ☐ Yes ☑ No

If yes, is there a dedicated dust recovery system in place? ☐ Yes ☐ No

Are methods employed to suppress dust or capture and recycle dust? ☐ Yes ☐ No

Explain: N/A

Firm ABC CORP Site LOS ANGELES Date MARCH, 1991	Pollution Prevention Assessment Worksheets Proj. No. 1	Prepared By DGL Checked By PEP Sheet 1 of 1 Page 3 of 18

WORKSHEET
2b

WASTE MINIMIZATION: Material Handling

B. BULK LIQUIDS HANDLING

What safeguards are in place to prevent spills and avoid ground contamination during the transfer and filling of storage and blending tanks?

- High level shutdown/alarms ☐
- Flow totalizers with cutoff ☐
- Secondary containment ☑
- Other ☐

Describe the system: UNDERGROUND TANKS ARE LOCATED IN CONCRETE PITS; ABOVE GROUND TANKS ARE AUTOMATED WITH BERMS

Are air emissions from solvent storage tanks controlled by means of:

- Conservation vents ☐
- Nitrogen Blanketing ☐
- Absorber/Condensor ☐
- Other vapor loss control system ☐
- Adsorber ☐

Describe the system: NO SYSTEM

Are all storage tanks routinely monitored for leaks? If yes, describe procedure and monitoring frequency for above-ground/vaulted tanks: VISUAL INSPECTION WEEKLY

Underground tanks: VISUAL INSPECTION WEEKLY

How are the liquids in these tanks dispensed to the users? (i.e., in small containers or hard-piped.) HARD-PIPED TO MANUFACTURING AREAS.

What measures are employed to prevent the spillage of liquids being dispensed? EMPLOYEE TRAINING

Are pipes cleaned regularly? Also discuss the way pipes are cleaned and how the resulting waste is handled: N/A

When a spill of liquid occurs in the plant, what cleanup methods are employed (e.g., wet or dry)? Also discuss the way in which the resulting wastes are handled: WET METHOD FOR LARGE SPILLS - SQUEEGEE TO DRAIN; DRY METHOD FOR SMALL SPILLS - TOWELS TO TRASH

Would different cleaning methods allow for direct reuse or recycling of the waste? (explain) REUSE NOT ALLOWED PER GMP'S VOLUME TOO SMALL FOR RECYCLING

Firm ABC CORP Site LOS ANGELES Date MARCH, 1991	Pollution Prevention Assessment Worksheets Proj. No. 1	Prepared By DGL Checked By DEP Sheet 1 of 1 Page 4 of 18

WORKSHEET
2c

WASTE MINIMIZATION: Material Handling

C. DRUMS, CONTAINERS, AND PACKAGES

Are drums, containers, and packages inspected for damage before being accepted? ☑ Yes ☐ No

Are employees trained in ways to safely handle the types of drums and packages received? ☑ Yes ☐ No

Are they properly trained in handling of spilled materials? ☑ Yes ☐ No

Are stored items protected from damage, contamination, or exposure to rain, snow, sun and heat? ☑ Yes ☐ No

Describe handling procedures for damaged items: PLACE IN LARGE PLASTIC BAG, RETURN TO DISTRIBUTOR

Does the layout of the plant result in heavy traffic through the raw material storage area? (Heavy traffic increases the potential for contaminating raw materials with dirt or dust and for causing spilled materials to become dispersed throughout the facility.) ☐ Yes ☑ No

Can traffic through the storage area be reduced? N/A ☐ Yes ☐ No

To reduce the generation of empty bags and packages, dust from dry material handling and liquid wastes due to cleaning empty drums, has the plant attempted to:

- Purchase hazardous materials in preweighed containers to avoid the need for weighing? ☐ Yes ☑ No
- Use reusable/recyclable drums with liners instead of paper bags? ☑ Yes ☐ No
- Use larger containers or bulk delivery systems that can be returned to supplier for cleaning? ☐ Yes ☑ No
- Dedicate systems in the loading area so as to segregate hazardous from nonhazardous wastes? ☑ Yes ☐ No
- Recycle the cleaning waste into a product? ☐ Yes ☑ No

Describe the results of these attempts: DRUMS WITH LINERS O.K.

Are all empty bags, packages, and containers that contained hazardous materials segregated from those that contain nonhazardous wastes? Describe the method currently used to dispose of this waste: NO HAZARDOUS WASTES GENERATED BY PLANT, LAB HAZARDOUS WASTES PUT IN LAB PACKS AND REMOVED FROM FACILITY

Firm ABC CORD Site LOS ANGELES Date MARCH, 1991	Pollution Prevention Assessment Worksheets Proj. No. 1	Prepared By DGL Checked By DEP Sheet 1 of 1 Page 5 of 18

WORKSHEET 3

INPUT MATERIALS SUMMARY

Attribute	Description		
	Stream No. 1	Stream No. 1	Stream No. ____
Material Name/ID	SODIUM CHLORIDE	WATER (WFI)	
Source/Supplier	JT BAKER	MADE IN HOUSE	
Hazardous Component	N/A	N/A	
Annual Consumption Rate	50,000 Kg	1,000,000 L	
Purchase Price, $ per _____	$5/Kg	$4/L	
Overall Annual Cost	$250,000	$4,000,000	
Material Flow Diagram available (Y/N)	N	Y	
Delivery Mode[1]	TRUCK	PIPELINE	
Shipping Container Size and Type[2]	25LB DRUM	N/A	
Storage Mode[3]	WAREHOUSE	N/A	
Transfer Mode[4]	HAND TRUCK	PUMP	
Control Mode[5]	SIGN OUT	AVAIL. TO ALL	
Empty Container Disposal Management[6]	CRUSH & LANDFILL	N/A	
Shelf Life	2YR	N/A	
Supplier Would			
— accept expired material? (Y/N)	Y	N/A	
— accept shipping containers? (Y/N)	Y	N/A	
— revise expiration date? (Y/N)	Y DOWN GRADE	N/A	
Acceptable Substitute(s), if any	NONE	NONE	
Alternate Supplier(s)	SEVERAL		

Notes:
1. e.g., pipeline, tank car, 100 bbl tank truck, truck, etc.
2. e.g., 55 gal drum 100 lb paper bag, tank, etc.
3. e.g., outdoor, warehouse, underground, aboveground, etc.
4. e.g., pump, forklift, pneumatic transport, conveyor, etc.
5. e.g., on-demand to all, select people only, sign out.
6. e.g., crush and landfill, clean and recycle, return to supplier, etc.

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WORKSHEET
4

PRODUCTS SUMMARY

Attribute	Description		
	Stream No. 1	Stream No. 2	Stream No. ___
Name/ID	SALINE SOLUTION	PROTEIN SOLUTION	
Hazardous Component	—	—	
Annual Production Rate	1,000,000 L	3000 L	
Annual Revenues, $ ___	$9.5 MILLION	$230 MILLION	
Shipping Mode	TRUCK	TRUCK	
Shipping Container Size and Type	CARDBOARD BOX 3'x2'x1'	CARDBOARD BOX 3'x2'x1'	
On-site Storage Mode	WAREHOUSE	COLD STORAGE	
Containers Returnable (Y/N)	N	N	
Shelf Life	1 YEAR	6 MOS	
Re-work Possible (Y/N)	Y	N	
Customer would:			
— Relax specification (Y/N)	N	N	
— Accept larger containers (Y/N)	N	N	

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WORKSHEET
5

OPTION GENERATION: Material Handling

Meeting Format (e.g., brainstorming, nominal group technique) BRAINSTORMING
Meeting Coordinator DGL
Meeting Participants MAT, DEP, DLS

Suggested Waste Minimization Options	Currently Done Y/N?	Rationale/Remarks on Option
A. General Handling Techniques		
Quality Control Check	Y	
Return Obsolete Material to Supplier	N	SUPPLIER WOULD TAKE-BACK AND DOWNGRADE
Minimize Inventory	Y	
Computerize Inventory	N	NOT COST EFFECTIVE
Formal Training	N	TO ESTIMATE COST/BENEFIT
B. Bulk Liquids Handling		
High Level Shutdown/Alarm	Y	
Flow Totalizers with Cutoff	N	
Secondary Containment	Y	
Air Emission Control	N	LOOK INTO THIS
Leak Monitoring	N	COST ??
Spilled Material Reuse	N	AGAINST GMP
Cleanup Methods to Promote Recycling	N	EXAMINE SPILL TYPES
C. Drums, Containers, and Packages		
Raw Material Inspection	Y	
Proper Storage/Handling	Y	
Preweighed Containers	N	NEED TO WEIGH & VERIFY IN HOUSE
Soluble Bags	N	NO
Reusable Drums	Y	
Bulk Delivery	N	TO BE CONSIDERED
Waste Segregation	N	NO HAZARDOUS MANUFACTURED WASTE
Reformulate Cleaning Waste	N	

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WORKSHEET
6a

PROCESS DESCRIPTION

1. GENERAL

Aqueous Cleaning

Type of Aqueous Cleaner	Cleaning Procedure (CIP, manual wash)	Hazardous or Active Ingredient
Alkaline Sufactant	MANUAL	KOH, PHOSPHATES
Alkaline Cleaner	CIP	NaOH
Acid Cleaner		
Acid Sanitizer	CIP	H_3PO_4
Other		

How are spent cleaning solutions managed:

Biodegradable; disposed of in sewer	☑ Yes	☐ No
Treated on-site; disposed of in sewer	☑ Yes	☐ No
Transported off-site	☐ Yes	☑ No
Other	☐ Yes	☑ No

If yes, explain: MANUAL WASH SOLUTION TO SEWER, CIP SOLN'S NEUTRALIZED THEN TO SEWER

List waste streams generated by aqueous cleaning: TANK & EQUIPMENT CLEANING

Solvent Cleaning N/A

Type of Solvent Used	Cleaning Procedure	Hazardous or Active Ingredient

How are spent solutions managed:

Biodegradable; disposed of in sewer	☐ Yes	☐ No
Treated on-site; disposed of in sewer	☐ Yes	☐ No
Transported off-site	☐ Yes	☐ No
Other	☐ Yes	☐ No

If yes, explain: _____

List waste streams generated by solvent cleaning: _____

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WORKSHEET
6b

PROCESS DESCRIPTION

1. GENERAL (continued)

Disinfecting/Sterilizing

Type of Disinfectant Used	Disinfecting Procedure (Spray, Wipedown, etc.)	Hazardous or Active Ingredient
BLUE CHIP	WIPEDOWN	QUAT AMMONIUM CMPDS

How are spent disinfectants managed:

Biodegradable; disposed of in sewer	☑ Yes	☐ No
Treated on-site; disposed of in sewer	☐ Yes	☐ No
Transported off-site	☐ Yes	☐ No
Other	☐ Yes	☐ No

If yes, explain: EXCESS SOLUTION DUMPED TO DRAIN

Is ethylene oxide used for sterilization? ☐ Yes ☑ No

What type of pollution control equipment is used? _____

What is the percent (%) ethylene oxide captured? _____

What is the percent (%) chlorofluorocarbon captured? _____

List waste streams generated by disinfecting/sterilizing: EXCESS SOLUTION FROM DAILY FILL AREA WIPEDOWN

Venting

What large-volume liquid chemicals are stored on-site? ETHANOL

Are storage tanks with breathing vents used? YES

Do process vessels release vapors? YES

What chemicals are released through vessel vents? ETHANOL

What type of pollution control equipment is in place? NONE

What percent (%) of vent gases generated are captured? Ø

List waste streams generated by venting: ETHANOL VAPOR

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WORKSHEET
6c

PROCESS DESCRIPTION

1. GENERAL (continued)

Disposables

List the disposable items used in manufacturing: PLASTIC PIPETS, BEAKERS, ETC

Off-Spec Materials

List the production raw materials that have been disposed of due to being out-dated or off-spec: SODIUM CHLORIDE

List the products you manufacture that have been destroyed and disposed of due to being out-dated or off-spec: SALINE SOLUTION

How are these items managed? NaCl TO MANUFACTURER. SOMETIMES TRASH. SOLUTIONS ARE REWORKED

2. FERMENTATION N/A

Fermenter Information

Description of fermenter: _____

Identification number: _____

Type of growth media used: _____

Size of sump: _____

Frequency of sump cleanout: _____

Does sump fluid go to waste treatment tank? _____

How often is fermenter inspected for the following:

- Heat transfer fluid leakage: _____
- Agitator seal fluid leakage: _____
- Integrity of process connectors: _____
- Integrity of sterile barriers: _____

What is the length of the fermentation cycle? _____

Process Information

How is culture removed from fermenter? _____

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WORKSHEET
6d

PROCESS DESCRIPTION

2. FERMENTATION (continued)

Where does it go? _____

How are cells removed? _____

Is used media sterilized? _____ If so, how: _____

Are media, cell debris, or vent gas waste streams hazardous? _____

If yes, list hazardous components: _____

How are contaminated fermentation batches handled? _____

What is the fermentation yield percentage? _____

List the waste streams that are generated by fermentation: _____

3. CHEMICAL SYNTHESIS, NATURAL PRODUCT EXTRACTION, FORMULATION

Solvent-Based Processes

Solvent	Operation	Annual Usage
ETHANOL	PROTEIN SEPARATIONS	1,600,000 GAL

How are spent solvents managed: RECOVER AND RECLAIM BY DISTILLATION

List waste streams generated by solvent-based processes: SPENT ETHANOL SOLUTION CONTAINING DENATURED PROTEINS

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WORKSHEET
6e

PROCESS DESCRIPTION

3. CHEMICAL SYNTHESIS, NATURAL PRODUCT EXTRACTION, FORMULATION (continued)

Aqueous-Based Processes

What types of water are used in your plant?

Water for injection	☑ Yes	☐ No
Distilled water	☑ Yes	☐ No
Softened water	☐ Yes	☐ No
Municipal water	☑ Yes	☐ No
Reverse osmosis/Deionized water	☐ Yes	☐ No

What aqueous process solutions are generated or used?

Aqueous Solution	Type of Water	Operation	Annual Usage
SODIUM CHLORIDE	WFI	FORMULATION	1,000,000 L
lab REAGENTS	DISTILLED H_2O	LAB OPERATIONS	UNKNOWN

How are spent cleaning solutions managed:

Biodegradable; disposed of in sewer	☑ Yes	☐ No
Recycled on-site	☑ Yes	☐ No
Recycled off-site	☐ Yes	☐ No
Treated on-site	☐ Yes	☐ No
Treated off-site	☐ Yes	☐ No
Other	☐ Yes	☐ No

If yes, explain: SALINE SOLUTIONS RECYCLED ON-SITE IF OUT OF SPEC; LAB SOLUTIONS ARE PUT DOWN THE DRAIN

List waste streams generated by aqueous-based processes: SPENT LABORATORY REAGENTS

4. RESEARCH AND DEVELOPMENT

List disposable items used in R&D processes: MISC PLASTIC LABWARE

List other R&D wastes:

Process	Type of Waste	Current Waste Management Method
FILTRATION	FILTER MEDIA	TRASH/LANDFILL
PACKAGING WASTE	PAPER, PLASTICS	TRASH/LANDFILL

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WORKSHEET
7a

WASTE STREAM SUMMARY

Attribute	Description		
	Stream No. 1	Stream No. 2	Stream No. 3
Waste ID/Name:	CLEANING WASTE	ETOH VAPOR	PKG. WASTE
Source/Origin	TANK AND EQUIPMENT CLEANING	STORAGE TANK VENTS	WASTE PACKAGING MATERIALS
Annual Generation Rate (units/year)	150,000 GAL/YR	1000 GAL/YR	25000 LB/YR
Hazardous Component Name	—	—	—
Annual Rate of Component(s) of Concern	—	—	—
Annual Cost of Disposal	$1000	$1000	$10,000
Unit Cost ($/_____)	$0.0067/GAL	$1/GAL	$0.4/LB
Method of Management[1]	SEWER	AIR EMISSION	SANITARY LANDFILL

Priority Rating Criteria[2]	Relative[3] Wt. (W)	Rating (R)	R x W	Rating (R)	R x W	Rating (R)	R x W
Regulatory Compliance	8	5	40	9	72	4	32
Treatment/Disposal Cost	4	3	12	3	12	7	28
Potential Liability	7	5	35	5	35	5	35
Waste Quantity Generated	6	9	54	4	24	6	36
Waste Hazard	2	2	4	6	12	2	4
Safety Hazard	3	1	3	1	3	1	3
Minimization Potential	5	8	40	7	35	8	40
Potential to Remove Bottleneck	2	2	4	2	4	2	4
Potential By-product Recovery	0	1	0	1	0	1	0
Sum of Priority Rating Scores		Σ(RxW)	192	Σ(RxW)	197	Σ(RxW)	182
Priority Rank		2		1		3	

Notes: 1. For example, sanitary landfill, hazardous waste landfill, on-site recycle, incineration, etc.

2. Rate each stream in in each category on a scale from 0 (none) to 10 (high).

3. A very important criteria for your plant would receive a weight of 10; a relatively unimportant criteria might be given a weight of 2 or 3.

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WORKSHEET
7b

WASTE DESCRIPTION

1. **Waste Stream Name/ID:** ETHANOL VAPOR **Stream #** 2
   Process Unit/Operation STORAGE TANK EMISSIONS

2. **Waste characteristics (attach additional sheet with composition data, as necessary)**
   ☑ gas ☐ liquid ☐ solid ☐ mixed phase
   Density, lb/cu. ft. _____ High Heating Value, Btu/lb _____
   Viscosity/Consistency _____
   pH _____ flash point _____ % water _____

3. **Waste leaves process as:**
   ☑ air emission ☐ waste water ☐ solid waste ☐ hazardous waste
   ☐ other _____

4. **Waste generation is:**
   ☑ continuous HIGHER IN SUMMER TIME DUE TO HIGH TEMPERATURE
   ☐ discrete _____
   discharge triggered by: ☐ chemical analysis _____
   ☑ other (describe) TANK VENTING

   Type: ☐ periodic _____ length of period:
   ☐ sporadic (irregular occurrence)
   ☐ non-recurrent _____

5. **Generation Rate**
   Annual 1,000 ~~lbs~~ GAL per year _____
   Maximum _____ lbs per year _____
   Average _____ lbs per year _____
   Frequency _____ batches per _____
   Batch Size _____ Average _____ Range _____

6. **Waste Origins/Sources**
   (Fill out this worksheet to identify the origin of the waste. If the waste is a mixture of waste streams, fill out a sheet for each of the individual wastes).

   Is waste mixed with other wastes? ☐ yes ☑ no
   Is waste segregation possible? ☐ yes ☑ no

   If yes, what can be segregated from it? _____

   If no, why not? PURE VAPOR
   Input material source of this waste ETHANOL STORAGE

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WORKSHEET
8

WASTE MINIMIZATION: Reuse and Recovery

A. SEGREGATION N/A

Segregation of wastes reduces the amount of unknown material in waste and improves prospects for reuse and recovery.

Are different solvent wastes from equipment cleanup segregated? ☐ Yes ☐ No

Are aqueous wastes from equipment cleanup segregated from solvent wastes? ☐ Yes ☐ No

Are spent alkaline solutions segregated from the rinse water streams? ☐ Yes ☐ No

If no, explain: _____

B. ON-SITE RECOVERY

On-site recovery of solvents by distillation is economically feasible for as little as 8 gallons of solvent waste per day.

Has on-site distillation of the spent solvent ever been attempted? ☑ Yes ☐ No

If yes, is distillation still being performed? ☑ Yes ☐ No

If no, explain: _____

C. CONSOLIDATION/REUSE

Are many different solvents used for cleaning? ☐ Yes ☑ No

If too many small-volume solvent waste steams are generated to justify on-site distillation, can the solvent used for equipment cleaning be standardized? ☐ Yes ☐ No

Is spent cleaning solvent reused? ☐ Yes ☐ No

Are there any attempts at making the rinse solvent part of a batch formulation (rework)? ☐ Yes ☐ No

Are any attempts made to blend various waste streams to produce marketable products? ☐ Yes ☐ No

Are spills collected and reworked? ☐ Yes ☑ No

Describe which measures have been successful: _____

Is your solvent waste segregated from other wastes? ☑ Yes ☐ No

Has off-site reuse of wastes through waste exchange services been considered? ☐ Yes ☑ No

Or reuse through commercial brokerage firms? ☐ Yes ☑ No

If yes, results: _____

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WORKSHEET
9

OPTION GENERATION: Process Operation

Meeting Format (e.g., brainstorming, nominal group technique) BRAINSTORMING
Meeting Coordinator DGL
Meeting Participants MAT, PEP, DLS, MJS

Suggested Options	Currently Done Y/N?	Rationale/Remarks on Option
A. Substitution/Reformulation Options		
Solvent Substitution	N	NOT FEASIBLE
Product Reformulation	N	
Other Raw Material Substitution	N	
B. Cleaning		
Vapor Recovery	N	TO STUDY THIS FORETCH
Tank Wipers	N	
Pressure Washers	Y	
Reuse Cleaning Solutions	Y	FOR CIP ONLY
Spray Nozzles on Hoses	Y	
Mop and Squeegees	Y	
Reuse Rinsewater	Y	CIP ONLY-FINAL RINSE USED AS PRERINSE
Reuse Cleaning Solvent	N	
Dedicated Equipment	Y	
Clean with Part of Batch	N	
Segregate Wastes for Reuse	N	

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WORKSHEET
10

WASTE MINIMIZATION: Good Operating Practices

A. PRODUCTION SCHEDULING TECHNIQUES

Is the production schedule varied to decrease waste generation? (For example, do you attempt to increase size of production runs and minimize cleaning by accumulating orders or production for inventory?)

Describe: YES - SOMETIMES EQUIPMENT IS RINSED ONLY (NOT WASHED) BETWEEN RUNS THAT WILL GO TO ONE BATCH

Does the production schedule include sequential formulations that do not require cleaning between batches?

If yes, indicate results: SEE ABOVE

Are there any other attempts at eliminating cleanup steps between subsequent batches? If yes, results:

B. AVOID OFF-SPEC PRODUCTS

Is the batch formulation attempted in the lab before large scale production?	☑ Yes	☐ No
Are laboratory QA/QC procedures performed on a regular basis?	☑ Yes	☐ No

C. OTHER OPERATING PRACTICES

Are plant material balances routinely performed?	☐ Yes	☑ No
Are they performed for each material of concern (e.g., solvent) separately?	☐ Yes	☑ No
Are records kept of individual wastes with their sources of origin and eventual disposal? (This can aid in pinpointing large waste streams and focusing reuse efforts.)	☐ Yes	☑ No
Are the operators provided with detailed operating manuals or instruction sets?	☑ Yes	☐ No
Are all operator job functions well defined?	☑ Yes	☐ No
Are regularly scheduled training programs offered to operators?	☑ Yes	☐ No
Are there employee incentive programs related to pollution prevention?	☐ Yes	☑ No
Does the plant have an established pollution prevention program in place?	☐ Yes	☑ No
If yes, is a specific person assigned to oversee the success of the program?	☐ Yes	☐ No

Discuss goals of the program and results:

Has a pollution prevention assessment been performed at this plant in the past? If yes, discuss:

NO

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WORKSHEET
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OPTION GENERATION: Good Operating Practices

Meeting Format (e.g., brainstorming, nominal group technique) BRAINSTORMING
Meeting Coordinator DGL
Meeting Participants MAT, DEP, HTM, JEG, DLS

Suggested Options	Currently Done Y/N?	Rationale/Remarks on Option
A. Production Scheduling Techniques		
Increase Size of Production Run	Y	COULD GO LARGER
Sequential Formulating	Y	
Avoid Unnecessary Cleaning	Y	CLEANING USUALLY NECESSARY
Maximize Equipment Dedication	Y	
B. Avoid Off-Spec Products		
Test Batch Formulation in Lab	Y	
Regular QA/QC	Y	
C. Good Operating Practices		
Perform Material Balances	N	ENGR. TO DO THIS
Keep Records of Waste Sources & Disposition	N	PROD'N TO DO THIS
Waste/Materials Documentation	N	PROD'N TO DO THIS
Provide Operating Manuals/Instructions	Y	
Employee Training	Y	
Increased Supervision	Y	
Provide Employee Incentives	N	TO BE CONSIDERED
Increase Plant Sanitation	N	
Establish Pollution Prevention Policy	Y	ENGR/PROD'N TO DO THIS
Set Goals for Source Reduction	Y	ENGR/PROD'N TO DO THIS
Set Goals for Recycling	N	
Conduct Annual Assessments	Y	FORM WM TEAM