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WASTE STREAMS AND INTEGRATED RESOURCE RECOVERY SYSTEMS IN DEVELOPING COUNTRIES

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Executive Summary

Among the many problems facing developing countries today, health now and in the future perhaps looms largest. As the population increases, so does the demand for protein sources and waste treatment. Integrated resource recovery is a solution to both problems that has excellent prospects of staying within the economic and technical constraints of a developing nation. This report surveys present technologies that can be combined to form an integrated system and reviews implementations of such systems. It also presents the results from research in Israel and other nations concerning new refinements and developments of the component processes and their integrations.

The first chapter of this report presents a problem overview and examines general types of waste disposal and the economic justifications for waste recovery. The second chapter describes the composition of the various waste streams considered: domestic liquid and semi-liquid wastes, solid wastes, animal wastes, agricultural wastes, and industrial and agro-industrial wastes. It is shown in these two chapters that a significant amount of recoverable material is available to present-day recovery technologies.

Chapter three briefly discusses traditional, non-integrated treatment processes and their inefficiencies in recovering various resource materials.

Chapters four and five form the core of the report with their discussion of IRR (Integrated Resource Recovery) system components, current examples of integration and proposed improvements in the current systems. Biogas generation and aquaculture receive the greater amount of attention since these processes promise the greater benefits. Waste stabilization ponds and the microbial ecology of methanogenesis are briefly discussed. Chapter five details some new ideas in modifying present processes to work more efficiently in an integrated system. The Israeli "combie" is just such an example; it is a long narrow pond that is, in effect, a continuous series of anaerobic, facultative and aerobic waste stabilization ponds. In the first part of the "pond," anaerobic fermentation yields methane gas while further down in the aerobic length, algae can be efficiently cultured.

Chapter six examines the health problems of using these intermediate technologies. Particular attention is paid to health risks in using effluent from the IRRS as irrigation water. While there is a 90-95% reduction in pathogens, it is recommended that the effluent be used to irrigate crops that are not eaten raw or partially cooked.

The economic and social consideration of implementing an IRRS are examined in Chapter seven. The question of how and to whom the benefits of an integrated resource recovery system are to be distributed are discussed for the particular case of biogas. Local customs and prejudices may not permit composting and methane generation using human excreta. Caste system restraints on social cooperation in India may prove to be a serious obstacle in the efficient implementation and operation of an IRRS in a small town or large village.

INTEGRATED RESOURCE RECOVERY SYSTEMS FOR
URBAN RESIDUAL STREAMS IN DEVELOPING COUNTRIES

I. Background

1. Introduction

As the population pressure increases in the rural areas of developing countries, many of the rural poor move to small and medium sized cities, causing an overload on the existing sanitation system. The predictions are for the situation to get much worse, with perhaps one billion more people in cities and towns by the end of the century (World Bank Annual Report, 1979). The UN has recognized these problems as being of paramount concern to the well-being of the world's population, and the 1980s have been designated the International Drinking Water and Sanitation decade. The World Bank, IDRC, and AID all have been concerned with these problems for some time. For example, the World Bank and IDRC recently completed a worldwide search to identify various intermediate technologies for wastewater treatment (IDRC, 1980), and the World Bank sponsored a WORD eleven other studies under a program on Appropriate Technology for Water Supply and Sanitation. The functions of these reports are discussed at various points in our study. The Environmental Sanitation Information Center of the Asian Institute of Technology in Bangkok has also recently completed a survey of human and animal waste management strategies in developing countries (see Environmental Sanitation Information Center (1981)).

Considerable work and numerous studies have been performed in the last three decades on improving health and sanitation conditions while at the same time maximizing resource recovery, reclamation, reuse and recycling in the rural areas of developing countries. The emphasis has been on

rather small rural communities of less than 2,000 inhabitants in relatively remote locations where the level of technology and availability of capital investment are at a very low level.

A large percentage of the population in developing countries lives, however, in small, medium and large urban areas or in large rural and semi-urban communities. Moreover, there is an accelerating and rather uncontrollable migration of population from the rural areas to the bigger cities and townships (World Bank Annual Report, 1979). This migration pattern creates new satellite communities, some of them mushrooming slums, around medium and large size cities. The resulting population densities produce critical health conditions and environmental hazards to the urban and semi-urban population. These hazards tend to be more severe than those occurring in the already established small rural communities (WHO Annual Report, 1978). Intensive agricultural activities at the fringes of the urban and semi-urban communities inevitably develop to supply the concentrated population centers with fresh produce (vegetables, fish and meat); owing to poor transportation systems and a lack of refrigeration facilities, the necessary quantities of produce cannot be brought from distant agricultural areas. Some of the agricultural activities are linked to and depend upon the "supply" of urban residues such as sewage, night-soil and refuse from the dense population centers. The uncontrolled nature of this source of fertilizer further aggravates the health and sanitation conditions of both the city residents and the neighboring semi-urban communities. For example, the flow of some 60 m^3/sec of untreated raw sewage from sprawling Mexico City is the major source of irrigation water for the agricultural belt surrounding the city; at present, it is a major health hazard to city dwellers, tourists, and

inhabitants of the farm communities around the city (SRH, Mexico City, Priv. Comm., 1981). The disposal of sewage and other municipal wastes from cities like Mexico City, Lima, Peru and Cairo, Egypt, to the surrounding lands, while providing some livelihood to slum dwellers through scavenging, inevitably poses major health hazards and almost intolerable sanitation and environmental conditions. This situation most affects the slum inhabitants but also constitutes a major epidiomilogical threat to the city itself.

In the past, the problem of liquid and solid waste disposal in urban areas of developing countries has been completely neglected, ignored, or approached by attempting to apply collection, treatment and disposal technologies used in the affluent, developed countries of Europe and North America. Urban communities in developing countries have been occasionally approached by representatives of European and American companies and international engineering consulting firms who promoted solving sanitation problems by constructing and installing sophisticated, expensive collection and treatment schemes. These efforts were sometimes encouraged by local authorities and private sectors who were either genuinely interested in "modernizing their cities" or had other interests. Fortunately, very few of these sophisticated solutions have been constructed since they would have imposed a financial burden beyond the means of the community. Moreover, such systems demand highly technical personnel for proper operation and maintenance. There is a tremendous shortage of this personnel in such countries. While the initial investment might have been provided by international funding organizations (although to be repaid in time by the community), the operating and maintenance expenses of such sophisticated technologies could not have been met by the community. Indeed, some of the conventional sewage treatment plants or refuse mechanical composting plants

which had been constructed in various cities in developing countries had to be abandoned or bypassed or their operation and peformance proved to be a far cry from their original design (WHO Annual Report, 1979). This is particularly true in the major cities (usually the capitals or major tourist centers) in developing countries. The problem of small and medium size cities has usually been ignored, most often because of the lack of financial means and political power of provincial cities.

The purpose of this work is to analyze integrated disposal/recovery methodology for population centers ranging from 5,000 to 250,000 inhabitants. The smaller are generally agricultural communities and the larger are generally urban communities surrounded by intensive agricultural semi-rural fringes.

While we do not believe that the integrated recovery systems for urban wastes will solve all of the problems of sanitation in the rapidly expanding towns, cities, and metropolises of the developing world, we do believe that these systems can make a large contribution in the area of public health planning and management. By controlling urban solid and liquid wastes, many disease vectors such as rats, flies, etc., can be effectively controlled. The recovery systems should also have a positive impact upon the financing of urban facilities, a factor that will become increasingly important as the competition for urban funds among transportation, housing, and other urban needs intensifies in the next twenty years.

Resource recovery systems are not to be emphasized solely for their synergistic effect on the economy of the collection and treatment operation or the need for recovery of energy fertilizers or food, but without the creation of positive-value commodities such as biogas, fertilizers,

animal-feed, recovered metals or fish and meat, the community might not perform at all the health and sanitation-oriented functions of collection, treatment and disposal. This is because it will not afford moving such functions of health and environmental damage prevention in its priority scale and it might not find enduring motivation and means to continuously operate the system once it is erected. Having an establishment of users (farmers, enterprisers, utilities, etc.) of the recovered material or resources is the surest guarantee that the operation of the system will continue with at least average performance.

The emphasis on integrated schemes for the treatment, disposal and recovery, as well as for possible collection and transportation of the wastes stems from the following premises:

1. Most domestic liquid or semi-liquid wastes (night soil, septage, sewage, sludge, sullage, etc.) contain a relatively high concentration of biodegradable organic matter (as measured by BOD_5). This is a result of lower water consumption per capita in most developing countries. Moreover, with the exception of piped sewage there is a relatively high solids content with a slurry-like consistency. Such consistency and composition facilitate the integration of the treatment, recovery and possibly the collection and transportation with other waste streams, most notably refuse and agricultural wastes.

2. The composition of solid wastes (refuse) is usually high in putrescible material and high in moisture content. Thus some of the techniques of treatment and recovery are similar to those of domestic liquid and semi-liquid wastes as well as agricultural wastes.

3. The organization of municipal services and administration is less fragmented than in developed countries (where sewage collection, treatment and disposal are usually totally separated from refuse handling). Thus, the collection and handling of both types of wastes can be done in an integrated fashion. Moreover, townships in developing countries in many cases encompass under their jurisdiction a large agricultural and semi-agricultural fraction which practices domestic animal husbandry. Unlike developed countries, the animal wastes are an important part of the wastes stream.

The work is divided in two parts:

(a) A state of the art analysis of the general situation in developing countries. This part does not attempt to review all the documented material (which is quite dispersed and occasionally contradictory) but to summarize the present thoughts based on experience and studies in various developing countries.

(b) The second part consists of a test case regarding the implementation of the approaches indicated in the first part. The test case involves Tacloban City, approximately 100,000 inhanitants, in Leyte, Philippines. This is reported on in more detail by Meta Systems (1983).

The objectives of the work are as follows:

- identifying and estimating the community waste streams that could become part of an integrated disposal/recovery system;
- determining alternative methods of collection for these waste streams;
- identifying the processes that could be used for converting various fractions of the waste streams (the inputs) into beneficial outputs;
- assessing the state-of-the-art of their economics and their appropriateness;
- determining the beneficial outputs for which there are local demands and estimating their demand and market price under different assumptions;
- determining the social and cultural acceptability of the various systems;
- identifying the most promising combination(s) of waste recovery technologies in medium-sized towns and discussing the institutional needs;
- determining other parameters that are controllable in the system.

2. General Types of Disposal Systems

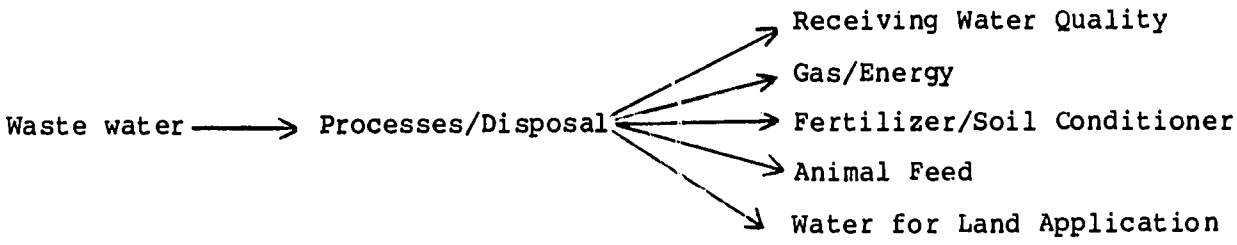
In the economically advanced countries community waste handling is usually viewed as a single-purpose activity with the goal of "environmental protection" through "end-of-pipe" treatment. Wastewater is assumed to have no economic value. Similar assumptions are made in handling urban solid wastes. The resulting system is illustrated for wastewater in Figure 1: the system's input consists of wastewater (of one type); the output is water quality protection; and the processes include wastewater collection and treatment facilities.

Figure 1: Conventional Urban Waste Disposal System

Waste water	Processes/Disposal	Fertilizer/Soil Conditioner

The design under these conditions is selected in such a way that capital costs (and operating costs) of the process train are minimized while satisfying the constraints on the output, such as environmental standards. In developing and underdeveloped countries, the assumption that the input to the system is "waste" with negligible value has recently been challenged, primarily because of the ever-increasing cost of energy and raw materials. This has led again to a change in the philosophy of disposal--actually returning to a philosophy that was practiced in developed countries like Germany and England until the 1960s. The single output of the process "environmental quality" is replaced by multiple outputs; in addition to environmental quality, there is energy in the form of methane from digesters, fertilizer from dried sludge cake, animal feed from harvested algae (from lagoons), and water for irrigation. This system of disposal/recovery is indicated in Figure 2.

Figure 2: Conventional Urban Waste Disposal/Recovery System



This system, with a single input and multiple outputs, demands important changes in planning and design because the following basic choices must be made:

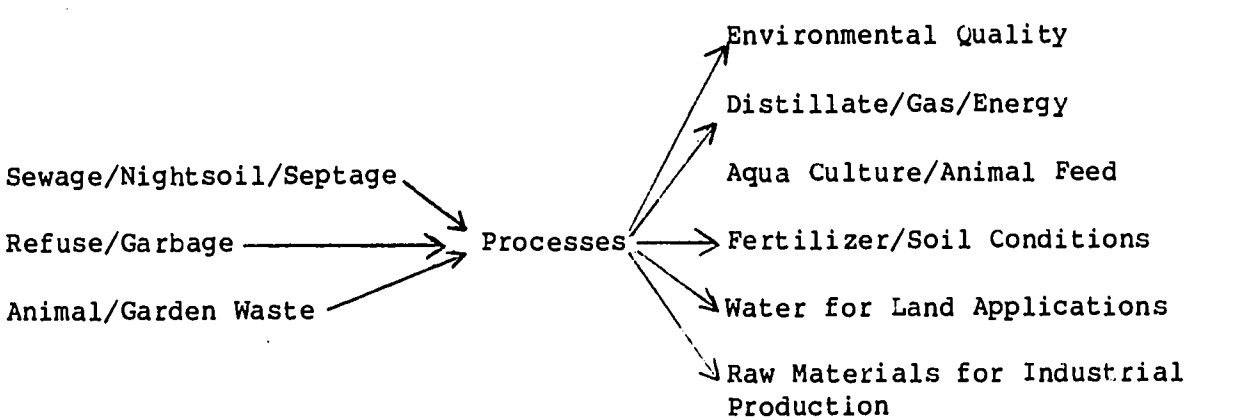
1. centralized versus decentralized collection, treatment, and disposal/reuse systems;
2. design of the process train of the reuse/disposal facility depending on the demand for potential end products; and
3. addition of auxiliary equipment in order to refine the recovered material for end use.

Typical examples are family biogas plants in a decentralized system and anaerobic digesters in a centralized system. Both of these examples produce gas as an energy source and sludges as a fertilizer-soil conditioner; however, the sequence of unit processes leading to the biogas and digester systems might vary. For example, in the centralized case, mixing primary and secondary sludge from a biological process, or having only primary sludge available from a physical treatment system, influences the gas generation and energy content of the unit. Bottling the gas and/or utilizing it for running pumping engines or generating electric power reflects the choice made regarding refinement of the recovered product.

Similar choices must be made with respect to the urban solid waste stream. Both the solid waste stream and the wastewater stream have in common the fact that their multiple output systems can no longer be simply designed by cost minimization; the design has become a multi-criteria problem, with important economic and social aspects.

The problem becomes even more complicated if, as has been speculated in the past few years, a system with multiple waste inputs from the community, instead of only wastewater or solid waste, is considered more appropriate for developing countries. Such inputs might include sewage, night soil, sullage, solid waste, and animal and agricultural wastes; the output becomes environmental quality as well as an array of beneficial products (Figure 3).

Figure 3. Potential Urban Multi-Waste Disposal/Recovery System



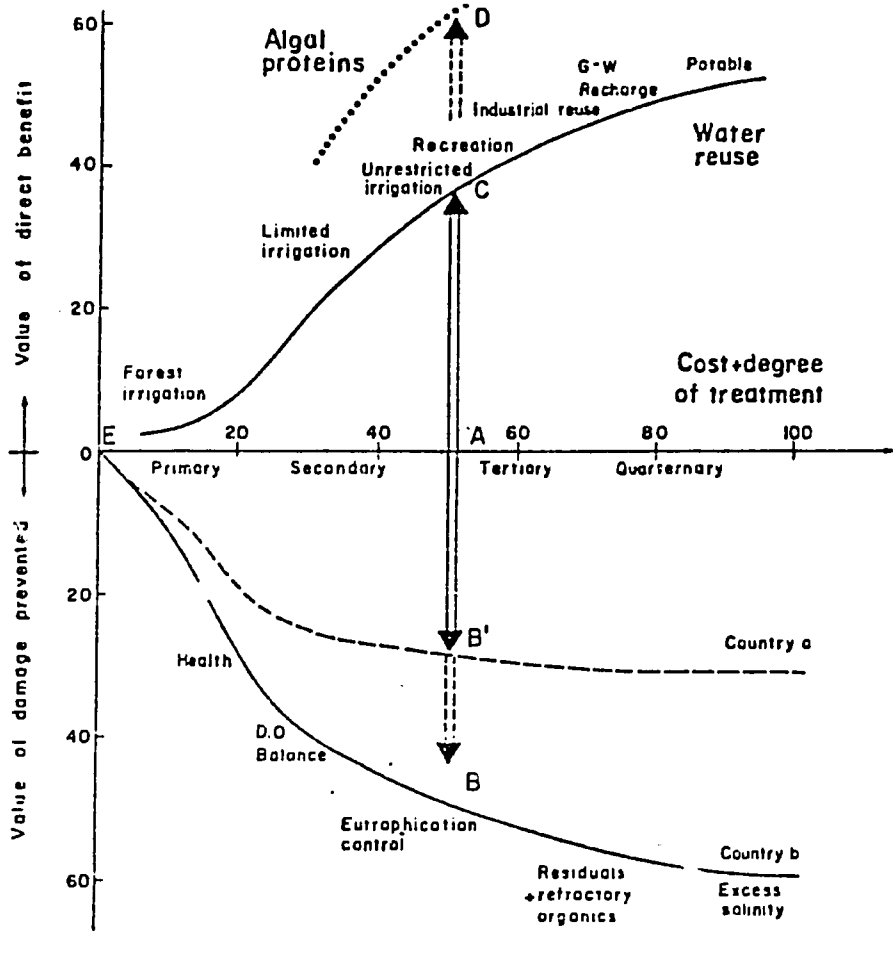
The rationale for such designs is based on expected scale economies (in a centralized system) and process compatibility for converting the several waste streams to beneficial outputs. Some research on centralized versus decentralized modes of these systems has been conducted with promising results in various developing and developed countries, such as India, the Philippines, Thailand, Israel, the United States, and Germany and is discussed in this report. The design and planning problems for these systems are far more diffcult than those for the previous two systems. Besides having to consider many different units for the processor and several demand functions for potentially beneficial outputs, decisions are needed on which waste streams to include as inputs. Altogether, the alternatives that must be analyzed and the technologies that must be developed and tested are numerous, which makes decision making difficult.

3. Basic Concepts of the Economical Justification of Treatment/Recovery Schemes

Figure 4 indicates schematically and conceptually the basic cost-benefit approach of waste treatment combined with resource recovery. Wastewater treatment was selected as an example in this scheme for the prevention of health and environmental damages while reclaimed water as well as recovery of algal proteins for animal feed were selected to illustrate the positive values of resource recovery. This example is more typical of the conditions in Israel where reclaimed wastewater is of high value to replenish the diminishing water resources and where animal proteins are in much demand. The degree of wastewater treatment is therefore higher than that which might be required in developing countries with lower GNP per capita.

The horizontal coordinate in Figure 4 shows in relative monetary units the increased cost of ascending treatment states (and also the degree of treatment and increased quality of effluent) starting with primary treatment, secondary (usually biological), tertiary--which includes nutrient removal, and quarternary--which includes removal of residual traces of non-biodegradable organic substances and possibly removal of excess salinity added to the wastewater by previous municipal use of the water. Other countries where the value assigned for reclaimed water is not as high as in Israel might assign a higher value for high quality effluent which is disposed to receiving bodies of water used for water supplies or for recreation.

Figure 4. Schematic Cost-Benefit Analysis of Wastewater Teatment, Reclamation and By-Product Recovery (Relative Cost Units)



Source: Shelef, Moraine and Oron, 1980.

The lower vertical ordinate shows the value of prevented damage by the progressing treatment level (using the same relative monetary units) starting with prevented health hazards and environmental damage (progressively improving dissolved oxygen balance, eutrophication hazards, etc.) and ending with removal of excess salinity.

The value of prevented damage is a subjective one according to priority value order in each society (country "A" vs. "B"). Israel, for example, is not as demanding in prevention of environmental nuisances (D.O. balance in streams) as some European countries. It is highly demanding, however, in protecting its diminishing water resources from excess nutrients (eutrophication) and salinity.

The upper vertical ordinate (value of direct benefit) gives the value of the renewed resources of water as it progressingly rises with the higher degree of beneficial use, which in turn is a function of increasing quality of the treated effluent. The added value of algae proteins (dotted line) gives an extra benefit as protein feed-stuff for animals. The total benefit (BD) is delineated by the sum of the values of prevented damage (arrow AB) and the value of the renewed resources of water and proteins (ACD) as compared to the cost of treatment (AE). Thus,

$$AB + AC + CD = BD$$

Only in a country which assigns a high value to health and environment (country "b") is AB AE, in this case the value of damage prevention by itself can economically justify the cost of the high degree of treatment.

In most cases, $AB + AC > AE$ or else $AB + CD < AE$, while $BD > AE$.

The positive value of renewed resources will economically justify a higher degree of treatment, thus bringing about a further improvement of environmental quality that otherwise would be beyond the means of the society.

The concept illustrated in Figure 4 is difficult to translate into an exact cost-benefit analysis since even the positive-value items such as water for consumptive uses such as irrigation or recreation and sometimes even proteins are usually subsidized by the government and their real value is hard to assess. The value of preventing poor health, poor sanitation and environmental damages is much harder to assess even in the highly developed countries and is almost impossible to evaluate in economic terms in developing countries.

II. Community Waste Streams

1. General Background

Current information on typical residual streams, encountered in communities of various sizes and different socio-economic characteristics, is not very extensive. Only a few samples have been made, even though the characteristics that describe the residual streams in terms of quantity and composition vary widely across communities and countries. Table 1 summarizes the type of residual streams with which we are concerned. In general, the relative magnitude of a stream changes with the size of the community. In villages and small towns, rural residuals (i.e., crop and animal residues) form the major flows, while in medium size and large cities the industrial residuals are the primary constituents.

Table 1. Potential Residual/Waste Streams

- Human feces/urine
- Animal dung/manure
- Residential solid residuals (including organic, paper, and inert fractions)
- Commercial residuals (for example, paper and cardboard, but also organic materials from fruit and vegetable markets)
- Industrial residuals (widely ranging in their characteristics, including agro-industrial wastes)
- Special wastes (such as hospital wastes)
- Agricultural/crop residue (of various types)
- Wood
- Street cleaning residue
- Urban stormwater runoff

Existing infrastructure does influence the residuals' composition. As shown by Gunnerson and Kalbermatten (1978), in most areas where water supply programs have been established, the sanitation programs generally lag far behind. If water supply programs are to achieve full health benefits, they must be accompanied by full-scale excreta removal programs. Thus, realization of health benefits implies a controlled waste removal program, which can be carried out in different ways. If pit latrines are used, a very high solids concentration exists; if septic tanks with small-bore sewers are installed, a very diluted solids concentration must be dealt with.

Residual streams characteristics have been estimated using various assumptions in the absence of measured samples. For example, use of coefficients, such as ratio of residue at field moisture to crop production, and unit animal residues (Table 2) in conjunction with local/regional socio-economic, human and animal population, and crop production data such as the one published by the State of Gujarat, India (1978) permit rough estimates to be made. Also, those characteristics important for processing, such as nitrogen (N) and carbon (C) for composting and biogas generation, have been derived from a limited information base.

Table 2. Unit Values for Residue

Agricultural Residues

Residue	Ratio of Residue at Field Moisture to Crop Production
Paddy straw	2.
Rice husks	0.25 of paddy
Rice bran	0.05 of paddy
Maize residue	2.5
Kenaf stick	2.
Bagasse	0.5

Animal Residues

Animal	Annual Manure Production (metric tons/dry wgt/head)
Cattle	1.00
Buffalo	1.25
Pig	.30
Fowl	.005

Source: Briscoe, 1975.

Jalal (1968) and Briscoe (1975) indicate that rice straw is the only suitable carbon-rich additive for biological processes and assume a moisture content of 5 percent and carbon and nitrogen contents of 38.2 percent and 0.5 percent respectively. Tables 3 and 4 show the wide range of estimates.

Table 3. Estimates of Quantity and Composition of Human Wastes in India

Source	Feces	Urine	Daily Grams per Capita Nitrogen Feces	Nitrogen Urine	Carbon Feces	Carbon Urine
Gotaas (1956)	204 (wet) 54 (dry)	950 (wet) 64 (dry)	3.2	10.8	27.2	8.9
Wagner & Lanoix (1958)	200-400	600-1130				
Bell (1973)	540					
Nawalinski (1975)	250					
Subrahmanyan (1975)	450-500 (wet) 50 (dry)	830				
Garg (1971)	133 (wet) 30 (dry)	1200 (wet) 64 (dry)	2.1	12.1		
Mohanrao (1973)	82 (dry)		3.3			
Acharya (1951)			1.5	8.6		
Snell (1938)	72 (wet) 20 (dry)	935 (wet) 51 (dry)	1.2	8.7	9.5	7.1

Source: Briscoe, J., "Public Health in Rural India: The Case of Excreta Disposal," Harvard Center for Population Studies, 1975, p. 68.

Table 4. Estimates of Quantity and Composition of Animal Wastes per Head of Cattle

Source		Dung Total lbs/day	Dung Dry Weight lbs/day	Dung Nitrogen lbs/day	Urine Total lbs/day	Urine Dry Weight lbs/day	Urine Nitrogen lbs/day
Gotaas	(1956)			15			
Garg	(1971)	36		40	10		33
Acharya	(1949)		6.0	27		1.4	54
New Alchemy Institute	(1973)	52	10	62	20		
Prasad	(1974)	22	7	46			
Mohanrao	(1947a)	21					
Parikh	(1963)	22	4.5				
Harris	(1974)	20					
Scott	(1956)	22		32	11		35
KVIC	(1975)	22					
Swaminathan	(1975)	22		16	8		18
Henderson	(1975)	38	7.6				

Source: Briscoe, J., 1975, p. 71

For a rather extensive animal farm unit, as found in the fringes of cities in both developing and developed countries Shelef (1979) has summarized the wastes output in Table 5. Numbers can widely vary from community to community according to the availability of household water supply, flush toilets or dry latrines, whether cows are in a closed floored shed or in the open forage, whether pigs are washed or not, etc.

Table 5. Material Output of a Model Farm Unit under Conditions of Developing Countries (A) and Developed Countries (B)

Source of Wastes	Volume m^3/day (A)	Volume m^3/day (B)	Volatile Solids kg(dry) per day (A)	Volatile Solids kg(dry) per day (B)	Nitrogen kg N/day	Phosphorus kg P/dry
5 humans (liquid and solid wastes)	0.56	1.00	38.0	38.0	0.1-0.3	0.013-0.05
12 cows	0.96	0.82	19.2	60.0	0.5-2.7	0.1-0.2
30 pigs (75 kg each)	0.75	1.84	35.4	35.4	1.9-3.2	0.2-0.6
2,000 hens (2 kg each)	0.08	0.12	38.0	38.0	1.4-2.9	0.4-0.9
Total	1.65	3.78	95.4	139.0	3.9-9.1	0.70-1.75

Source: Shelef, G. (1979)

Given the size of the communities with which we are concerned, the flow of urban solid wastes is typically not very large. There is organic matter, especially residuals from market operation, but cans, bottles, plastics, and other items found at such high percentages in the developed countries are almost nonexistent in India and many developing countries. Very seldom are they detected at the local dump site, because there are internally reused. The same is true with paper. In general, the more rural a community, the higher the recycling rate; the more urban the community, the more "waste items" entering the flow.

In both developed and developing countries the lack of information on urban refuse is common. Pickford (1976) has summarized results from samples in a few large cities (Table 6). Briscoe assumed, on the basis of an Indian survey of quantity and composition of refuse and data collected

by Acharya and reported by Flintoff (1976), that approximately 366 grams of refuse per capita per day is collected (with a moisture content of 20 percent and a carbon and nitrogen content of nearly 22 percent and 0.6 percent, respectively, of the dry weight). This would be a lower bound because the amount collected is generally smaller than that generated and the lower moisture content indicates that the wastes have passed through a period of considerable drying before the analysis was made.

An integrative assessment of the potential change of living conditions due to a switch to alternative fuels becomes of great importance in designing the solid waste management system. For example, because of the use of a specific coal briquet for cooking (with about 50 percent clay/minerals), the wastes of Pusan, Korea, are very different from those in areas using other fuels for cooking and heating. In general, the more populous the community, the greater the energy consumption. This consumption is weighted towards "commercial" fuels in large communities, even among the poor. For example, Cecelski, et al. (1979) reported that "commercial" fuels (mainly soft coke and electricity) account for 60 to 70 percent of consumption (by quantity) in Calcutta and Delhi -- a much higher proportion than in rural areas.

TABLE 6. COMPOSITION OF TOWN REFUSE

Place	World range	Bankok, Thailand		Calcutta, India		Deshpara India	Delhi, India	India	Enugu Dubai	Ibadan Nigeria		Madras Nigeria	Nagpur, India		Poona India	UK	USA
Date	1971	1957	1970	1970	1964	1970	1974	1973	1973	1972	1972	1970?			1970?	1968	1972
Note (see below)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Fruit and vegetable	5-90	47.5	2.6-5.1	16.0	14	20	20.3	40				57	3.8	4-6	68	1,706	
Leaves, grass, straw wood, coconut sheels			6-75	18.0		21			83	80.7	9.6		12.9	4-6			9
Food wastes		0.7							9.1	9.1	70.3						14
Paper and cardboard	0.25-55	4	7-13	3.2			5.9	25.5		3.4	10.0	4.8	2.0	3-6	8.7	36.9	55
Rags		5.4	0.3-0.6	3.6	2	1	3.6	8.09	4.1	4.1	1.6	3.8	0.6	3-7	1.6	2.4	3
Glass, crockery, bones		1.9	1.6-6.9	7.4	4	1	0.6	5.0		0.5	2.5	0.5	0.2	0.3-0.8	0.6	9.1	9
Metal, tins		2.3	0.8-1.3	0.7	4		0.6	12.5	2.3	2.3	5.9					8.9	9
Plastics	0.1-7		2-7	0.6			0.5	4.5				0.6	0.3	0-2	0.7	1.1	1
Dust, ash, cinder		24.1		41.6	69	57	6.0									21.9	
Miscellaneous		14.1			7			4.5	1.0							2.1	
Moisture content				41			14.7			43-65			42	10-32			
Weight per person kg/d	0.2-3			0.51	0.39	0.32	0.31			0.4-0.6		0.56			0.3	0.80	2.6
Density			0.163-0.335	0.52-0.57	0.46	0.38	0.47			0.28		0.435			0.298	0.157	
Volume per person l/d				1.08	1.18	0.85	0.66			1.4		1.29			1.0	5.1	
Calorific value kJ/kg				6,300		1,400	6,600					6,700	5,300	4,600	7,100	8,000-16,500	

1. WHO Expert Committee (1971).
2. Surveyor (1958).
3. Information from Professor M.B. Pescod.
4. Central Public Health Engineering Research Institute (1970).
5. Chosh et al. (1964).
6. Rao et al. (1970).
7. Bijlani et al. (1974).
8. Information from J.D. and D.M. Watson.
9. Information from Enugu Municipal Council
10. Ibadan Old Town. Oluyemi (1972) and Oluwande (1974).
11. Ibadan reservation, Oluyemi (1972).
12. Information from CHERI.
13. Bhide and Muley.
14. Bide, Mottghave, Patel and Gautam.
15. Information from CHERI.
16. Department of the Environment (1971).
17. Davoll (1972).

Source: Pickford, "Solid Waste in Hot Climates," in Water, Wastes and Health in Hot Climates (R. Feachieu et al., eds.), John Wiley Press, New York, 1976, p. 322.

2. Domestic Liquid and Semi-liquid Wastes

The volume of material produced per capita per day and the composition depend to a large extent on the household sanitary services. The following types will be considered: 1) night soil, 2) dry latrines, 3) flush latrines with general septic tank-leaching pit, 4) flush latrines with "black water" septic tank, and 5) modern sanitation (flush latrines and piped sewage). A recent World Bank report by Mara (1982) gives an excellent overview of the options available for domestic sanitation in developing countries.

a. Night Soil

Human excreta (feces and urine) is collected daily by a private or public service. For design purposes the following quantity and compositions are assumed (Table 7).

Table 7. Assumed Quantity and Composition of Night Soil*

	Grams per Capita per Day
Wet material	1200
Dry material	120
Volatile matter (dry)	102
Biochemical Oxygen Demand (BOD), 5 day at 20°C	45
Nitrogen	12
Phosphorus	1.6

*Note: Data in Tables 7-11 were collected from various papers and the author's experience.

b. Dry Latrines

Usually an outdoor pit in the ground with a temporary structure serves as the dry latrine. Material output varies considerably according to local conditions and customs. In very densely populated areas these latrines are emptied occasionally, while in other areas a new pit would be dug and the "outhouse" would be moved over the new pit. The quantity of material, its consistency and composition depend on frequency of emptying, soil leaching, degree of coverage, whether quick lime is used as a disinfectant and fly control, or whether sand is used for intermittent covering, climatic conditions and ground water level. In any event, considerable decomposition and drying usually take place in the pit with a large portion of the nitrogen lost through ammonia evolution into the atmosphere (this is increased when lime is applied). The average quantities and composition are given in Table 8.

Table 8. Assumed Quantity and Composition of Dry Latrine Output (Assuming 60% emptying rate and infrequent liming)

	Grams per Capita per Day
Wet material	250
Dry material	80
Volatile matter	45
Biochemical Oxygen Demand (BOD), 5 day at 20°C	18
Nitrogen	4.5
Phosphorus	1.2

c. Flush Latrine with General Septic Tank-Leaching Pit

Once water supply is introduced into the household, a certain proportion of the family units install a flush toilet in addition to a kitchen sink and sometimes a shower. In most small and medium-sized provincial cities in developing countries no piped sewerage exists, or only a certain part of the city is served by this method. Some sort of septic tank followed or combined with a leaching pit (very rarely leaching field) serves for wastewater disposal from the household. In most instances, leaching rates decrease with time even in sandy soils due to build-up of decomposed polysaccharides, grease, and other organic decomposition by-products. The rate of soil clogging and leaching reduction can be very rapid in heavy soils (clay) and when groundwater level is high. The failure of most leaching arrangements in urban areas is one of the major health and sanitation hazards in developing countries since the septic overflow would soon fill the courtyard, seep to the street and find its way to the open drain (hopefully not to the nearest well).

Regular emptying of septic tanks is necessary although only the upper middle class and wealthier people can afford this service. The cost of this service is quite high and vacuum tanks or trucks are both expensive and require reliable operation and maintenance.

The quantities and composition of waste output depend on many factors, among them: a) the degree of leaching, b) retention time in the septic tank, c) the degree of liquid overflow, and d) method of emptying.

Assumed quantities and composition of this septage are given in Table 9. In this table a liquid recovery of 75 percent as well as partial decomposition of the organic matter is assumed.

Table 9. Assumed Quantity and Composition of General Septage

	Grams per Capita per Day
Wet material	80,000
Dry material	100
Volatile matter	90
Biochemical Oxygen Demand (BOD), 5 day at 20°C	35
Nitrogen	7
Phosphorus	1.5

d. Flush Toilets with "Black Water" Septage

The treatment and recovery method of separate "black water" septage tanks as proposed by Shelef (1976) is recommended for households that have flush toilets (not yet served with piped sewerage) to overcome hauling and handling costs. "Grey water" from kitchen sink, laundry and shower (or bath) is discharged to a leaching pit (or field) with or without a preceeding septic tank treatment. The grey water has a low concentration of organic matter and usually clogs the leaching pit or field at a slower rate. After long continuous use some of the grey water will nevertheless overflow, but this overflow can be diverted into an irrigation ditch in the courtyard or around the house or can be directed into the flood drain. Grey water does not contain human excreta and therefore is not a very important source of pathogens, malodors, or other nuisances. The "black water"

from a flush toilet is discharged into a relatively voluminous septic tank which can periodically be emptied by a proper private or municipal service. A leaching pit can be connected to the septic tank to remove excess liquid. It is assumed that any leaching arrangement will finally clog and at least 75 percent of the material should be emptied. It is recommended that two-stage toilet flush systems (or "niagras") be used to minimize the black water flow. Thus, the first stage is used for urine and it discharges about 2 liters per "small flush" while the second stage is aimed at flushing fecal matter with a discharge of 5 liters per flush. With a two-stage arrangement the black water discharge per capita per day can be lower than 20 liters per day.

The separation of grey water and black water, while not environmentally ideal, can still improve sanitation conditions many-fold. It should be noted that overflow grey water after some retention in the pit contains 4 to 6 orders of magnitude less pathogens than black water.

Table 10 summarizes the assumed quantities and composition of black water. Some decomposition occurs in the black water septic tank between emptyings, which explains the lower percentage of volatile matter. It is further assumed that 75 percent recovery of the volume will take place and the rest will leach or seep.

Table 10. Assumed Quantity and Composition of Black Water Septage

	Grams per Capita per Day
Wet material	14,000
Dry material	80
Volatile matter	65
Biochemical Oxygen Demand (BOD), 5 day at 20°C	30
Nitrogen	8
Phosphorus	1.6

e. Modern Sanitation with Piped Sewerage

Sections of the city might be connected to a sewerage system. Usually the new commercial hotels and affluent sections are connected first while the older sections, the sprawling fringes and the slums are connected last (if ever).

The assumed quantities and composition of this sewage are given in Table 11.

Table 11. Assumed Quantity and Composition of Wastewater in Piped Sewerage

	Grams per Capita per Day
Wet material	130,000
Dry material	170
Volatile matter	135
Biochemical Oxygen Demand (BOD), 5 day at 20°C	60
Nitrogen	12
Phosphorus	1.8

3. Solid Wastes (Refuse)

General Background

As shown in Table 6, the quantities and composition drawn from the various studies of larger urban areas in developing countries quoted by Pickford (1976) vary widely. Unlike the developed countries of Europe and North America, domestic and commercial (usually from markets) solid wastes in developing countries contain an appreciable proportion of putrescible matter as compared to paper and cardboard, glass, metals, plastic and textiles (rags). However, in many smaller townships and especially in the semi-agricultural fringes of cities, where domestic animals such as cattle, water buffalo, pigs, donkies, goats, dogs and poultry are in close proximity to the household, a large part of the domestic food-wastage and vegetative matter is fed to these animals. Many households in Thailand, Taiwan, the Phillipines, China, and Indo-China, for example, are feeding courtyard pigs with most of the household refuse. In Mid-Eastern Moslem countries the family goats scavenge a good portion of the vegetative wastes, but meat scraps and bones are devoured by dogs. Other parameters important for design of treatment/recovery schemes such as moisture content and density vary from location to location according to climatic conditions, type of storage (closed or open bins), frequency of collection, etc. Even refuse from commercial centers in the more developed cities will contain much less cardboard and packing material; it is usually returned or collected by scavengers. Most glass bottles are returned for reuse (a relatively high deposit is charged for glass bottles) and even refuse from well-to-do sections of town is sorted for valuable material by household servants

before collection for disposal. In some cities in the Middle East, private collectors are performing the collection services gratis for the value of the materials (including the putrescible part which is fed to goats, donkies and mules).

Quantities and Composition of Solid Wastes

For establishing solid wastes output criteria for the proposed integrated treatment/recovery scheme, the following composition and quantities are assumed, as compared with average data in the U.S., Western Europe and Israel (Table 12).

Calorific Value

The nitrogen and phosphorus content of solid wastes can be assumed as 4 and 0.45 percent of the dry putrescible matter, respectively. Thus, an average contribution of 3.5 and 0.4 grams per person per day of nitrogen and phosphorus, respectively, can be assumed to be contributed by the solid wastes. In considering incineration or pyrolysis, the calorific value of the wastes is most essential. Almost no direct measurements data (using large-size bomb calorimeters) are available in developing countries.

A good approximation can be reached by using the composition data and the heat value of the refuse components, summarized in the following equation:

$$E = (M_i - W_i)Ed_i - [(100 - T) + 540] \; W$$

where: E is the calorific value in kcal of one kg of raw (wet) solid wastes

Table 12. Composition and Quantities of Typical Municipal Solid Wastes in Developing Countries as Compared with Developed Countries

Location	Developing Countries	U.S.A.	Western Europe	Israel
Composition	Percent weight (wet basis)			
Food and vegetative wastes (putrescible)	68	16	24	60
Paper and cardboard	7	46	38	17
Plastic, leather and rubber	3	5	7	9
Glass and ceramics	2	11	9	3
Rags and textiles	2	3	4	2
Metals (ferrous and nonferrous)	3	9	6	4
Miscellaneous combustibles	3	3	3	2
Cinder, sand, dust, rocks and misc. incombustibles	12	7	9	3
Total	100	100	100	100
Moisture Content	percent			
Average	63	23	28	62
Range	35-78	15-32	20-40	50-75
Quantities	kg per Capita per Day			
Average	0.52	2.3	1.10	0.96
Range	0.2-0.75	1.8-2.8	0.8-1.5	0.7-1.2
Density	kg/m^3			
Average	430	190	2100	320
Range	150-580	130-230	160-270	190-430

T is the average temperature in °C of the solid wastes (usually taken as 40°C in warm countries due to the self-heating of the putrescible refuse.

M_i is the weight fraction of each given component (i) in one kg of raw (wet) solid wastes.

W_i is the weight fraction of water of each given component (i) in one kg of raw (wet) solid wastes.

Ed_i is the calorific value in kcal per kg of the dry component (i) in the solid wastes.

The calorific value of the average solid wastes assumed for developing countries shown in Table 12 is given in Table 13.

Table 13. Estimation of the Calorific Value of Typical Solid Wastes in Developing Countries (see Table 12)

Component	M	W	M-W	Ed	(M-W)Ed
Putrescible matter	0.680	0.510	0.170	4020	683
Paper and cardboard	0.070	0.030	0.040	4500	180
Plastics, rubber and leather	0.030	0.006	0.024	7200	173
Rugs and textiles	0.020	0.010	0.010	4400	44
Misc. combustibles	0.030	0.013	0.017	3900	66
Noncombustibles	0.170	0.061	0.109	--	--
	1.000	0.630	0.370	--	1146

The calorific value, E, is therefore:

$$E = 1146 - (60 + 540)0.63$$
$$= 1146 - 378$$
$$= 768 \text{ kcal/kg (wet)}$$

As shown in a later chapter, such calorific value is considerably lower than that necessary to justify incineration or pyrolysis as a means of energy fuel recovery from municipal solid wastes.

4. Animal Wastes

General Background

The amount and composition of the collectable part of animal wastes can widely vary according to the following factors:

1) Type of husbandry , degree of confinement, and type of feeding (open forage, scavenging, feed lots, concentrated mixed meal rations, roughage feeding, etc.)

2) Type of sheds (closed sheds, open sheds with yards, night time sheds, etc.)

3) Mechanism and frequency of waste collection and storage

4) Use of straw beds vs. concrete floors, corrals, slotted floors with pits, etc.)

5) Type and abundance of food (a significant part of the wastes is composed of uneaten food)

6) Climatic conditions

Thus, a stray cow in India will have much less collectable manure than a feedlot cattle in the Philippines and a courtyard sow in Thailand will produce much less collectable wastes than a similar one in Singapore where the wastes are collected in pits under slotted piggery floors.

Similarly, many developing countries, such as Thailand, Taiwan, the Philippines, and Malayasia are developing battery-type poultry farms around the big cities for both broilers and laying hens while in other locations (even in the same countries) household courtyard chickens are typical. When the manure is collected infrequently and part of it is allowed to dry, a major part of the nitrogen can be lost through ammonia evolution into the atmosphere.

For the integrated treatment and recovery scheme the assumed quantities and composition of wastes per animal are given in Table 14.

Table 14. Assumed Quantities and Composition of Collectable Animal Wastes for the Integrated Scheme

	Grams per Animal per Day			
	Cattle	Pigs	Chicken	Working Animals
Wet Material	18,000	8,000	50	7,000
Dry Material	4,000	1,000	20	2,000
Volatile Matter	3,250	820	16	1,500
Nitrogen	45	36	1.2	30
Phosphorus	6	3	0.2	4

5. Industrial and Agro-Industrial Wastes

The quantities and composition of these wastes can widely vary from location to location according to the type of industry and intra-industry recovery. Rice mills, for example, can produce large quantities of dry carbonaceous rice husks. It is good housekeeping to use such waste material within the industry as a source of energy or filling material. Breweries, distilleries, dairies, slaughterhouses and canning industries produce large quantities of concentrated biodegradable organic wastes that can be added to the treatment/recovery scheme. Tannery wastes can be problematic due to the high concentrations of chromium; these wastes should be segregated. Some general allowance of these wastes will be given in the description of the model treatment/recovery scheme.

6. Vegetative Wastes

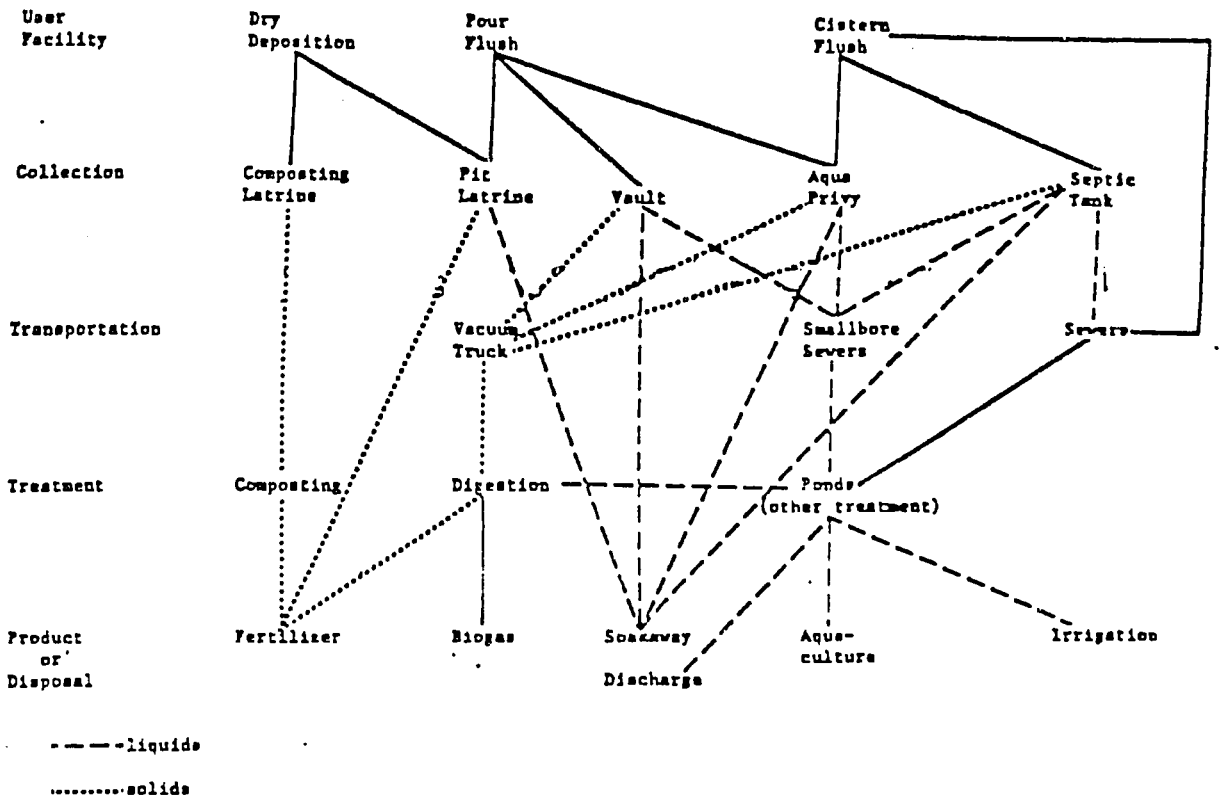
Crop residue such as cotton stems, coconut shells, rice husks, corn cobs, straw, etc. can be voluminous and can add much needed carbonaceous matter and dry solids to some of the integrated treatment/recovery disposal schemes, especially compostation. Since the quantities and composition can vary widely from location to location no specific estimates will be shown herein.

7. Collection and Transportation

a. General Review

The state of centralization or decentralization determines the collection and transportation mode. Figure 5 shows how collection/transportation/treatment are basically part of one process for the most decentralized system. Sophistication and costs increase substantially with centralization of the system.

Figure 5. ALTERNATIVE TECHNOLOGIES FOR EXCRETA MANAGEMENT

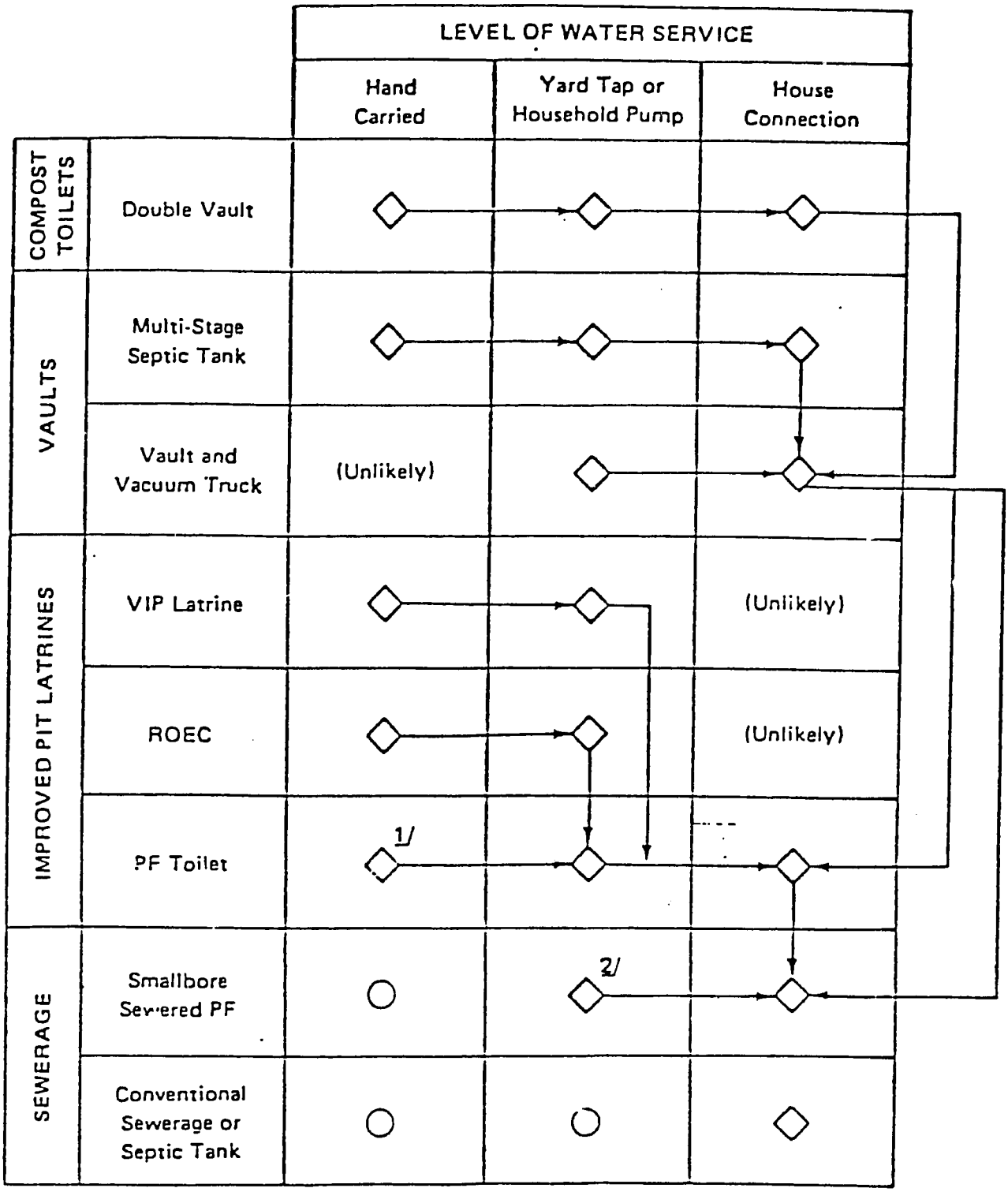


Source: J.M. Kalbermatten and D.S. Julius (1978), p. 142.

Nevertheless, it must be recognized that in urban areas collection and transportation (for example, of human excreta) as part of the sanitary infrastructure cannot be seen in a static sense. With increasing size and population density of urban areas, increasing centralization of infrastructure becomes necessary, which implies increasing transportation needs. Thus, utilization of an appropriate expansion scheme (called staging) is necessary in order to balance collection and processing of residuals reuse. Figure 6 documents some staged sanitation solutions. For example, a vault could be added to a standard pit privy with a power flush (implying trucks or small-bore sewers for collection) if housing density increases or soil becomes clogged. Similarly, a composting toilet with an already tight vault could be converted into an aqua-privy or pour flush privy with a vault (again implying a shift in collection).

Most of the costs associated with manpower and equipment can be estimated: the available cost figures are generally those for large urban centers. For example, the Indian Central Public Health Engineering Research Institute (Briscoe, 1979) has estimated that the cost of refuse haulage in Calcutta is about Rs. 1.84 per ton per mile; Popenoe (1975) has estimated transportation costs in developing countries to be between Rs. 1.7 and 2.5 per ton per mile in 1970; Jalal (1968) estimates a mixed refuse transportation cost of Rs 2.29 per ton mile; and Dave (1966) found the cost of hauling refuse in Nagpur to be Rs. 1.29 per ton mile. Similar costs can be assumed for transporting compost. Briscoe (1975) reports that the cost of transporting/collecting night-soil is Rs. 1.09 per ton per mile in the village of Chinnallapatti (Tamil Nadu), which has a population of 25,000. For the same town, the annual per capita cost for refuse collection is estimated at Rs. 2.80; 24 sweepers (bhangis) are

Figure 6. Potential Sanitation Sequences



Source: J.M. Kalbermatten, et al. (1979).

Key:

◇ Technically Feasible
O Technically Infeasible

1/ Feasible if sufficient PF Water will be hand carried

2/ Feasible if total wastewater flow exceeds 50 lpd

employed, and six collection units comprising a driver, a cart, and a pair of bullocks are organized. Since much larger cities (like Madras, with 600,000 people) exhibit similar annual per capita costs (Rs. 2.1), Briscoe (1975) suggests that per capita collection costs may be similar over a large range of city sizes. The town of Bharuch, Gujarat, for example, currently employs 210 sweepers, 92 working on the night soil from bucket latrines, and 34 supervisory and administrative staff at an annual cost of Rs. 1,237,000.

b. Piped Sewerage vs. Vehicular Hauling of Liquid and Semi-Liquid Wastes

One of the premises of the integrated treatment/recovery scheme is based on the high cost and impracticality of constructing a piped sewerage network in many (if not most) urban areas in developing countries.

The cost of piped sewerage network construction in the U.S., based on EPA (1978) data corrected to 1981, is between U.S. $800-2000 per capita in cities between 50,000 to 100,000. The size of the city does not affect the cost per capita very much since increased scale requires large diameter long mains and more force mains and pumping stations. Although the cost of labor is much lower in developing countries, the total construction costs of piped sewerage network might not be significantly lower than in the U.S. and in many instances can be significantly higher. Some of the reasons are as follows:

1. Many of the cities in developing countries are located in very flat plains, some of them in frequently flooded areas and high water tables, and heavy clay soils characteristic of river deposits. Such conditions require numerous pumping stations and force mains and pipe laying is very expensive and less reliable while pipe longevity is relatively short.

2. Constructing sewerage systems in existing old cities, particularly with narrow streets and high population densities is expensive, disruptive and involves risks to existing buildings.

3. The lower water consumption and the high concentration of sewage require higher pipe grades and slopes to facilitate gravity flow to maintain self-cleaning water velocities and to protect from clogging. The high water table, the lack of flood and rainwater drainage require larger diameter pipes than would be required by the sewage flow.

4. Pipes or pipe material, pumping stations and excavation equipment are in many instances imported and much more expensive than in the U.S., while manual excavation and pipe laying, especially in heavy soils and under high water tables, might prove more expensive than mechanical excavation and pipe laying despite the cheap labor.

It is estimated therefore that a city of 100,000 inhabitants will have to invest at least an equivalent of 100 million U.S. dollars for its sewerage piped network and will still face the problems of sewer maintenance and pumping station operation under unfavorable conditions. Such a magnitude of investment (a certain proportion in hard currency) is usually beyond the means of the local community or the given national government, it could constitute a major part of the nation's GNP and available investment resources and is hardly justified when compared to other local and national investment priorities such as industrial and agricultural development. Moreover, the cost effectiveness of major sewerage networks is further diminished when only part of the population has flush toilets while a major part of the population is still using dry latrines.

Two additional aspects should be considered:

1. As far as most integrated treatment/recovery schemes are concerned, the more concentrated the wastes the more cost effective and more technically feasible is the scheme.

2. Bearing in mind the conditions of severe unemployment that plague most developing countries today, the labor-intensive vehicular hauling of wastes (from hand carts to motorized vacuum trucks), even if proven to be of nominal cost, will support employment of otherwise umemployed sections of the population.

Since there is no chance or intention to stop the trend of furnishing households with running water and installing of flush toilets for increasing numbers of families, the solution could be found in the two-stage flush toilet combined with the segregation of black-water and grey water discussed in the previous chapter. Even by decreasing the collectable quantities of black water septage to about 12-15 liters per capita per day, the collection techniques of such thick slurries is still problematic. Mechanized vacuum tanks are expensive and hard to maintain.

Tractor or animal hauled basin-type open containers with capacity of 2 to 12 m^3 equipped with a submerged Mayno type pump, modified Archimedes screw pump or other positive displacement or peristaltic mechanisms are recommended. They can be motor driven, connected to the tractor's transmission or even hand or bicycle driven for smaller installations.

The hauling of moist semi-solid material as refuse, dry latrine material, manure and the like is usually done by simple wooden carts driven by hand, bicycle, animals, tractors or motor vehicles. Night soil is usually collected in buckets, old oil drums, basin-type open tanks, closed tanks and P.V.C. or fiber-glass tanks.

Due to the variations in vehicles, roads, distances, frequencies of collection and cost of manpower, animals and vehicles, no attempt is made here to arrive at costs of collection and transportation by hauling.

c. Total Quantities to Be Hauled

Based on various assumptions made in the previous chapter the total weight of the wastes to be hauled W_w is as follows:

$$W_w = L_w + S_w + A_w + I_w$$

where the weights of L_w, S_w, A_w and I_w are liquid, solid, animal and industrial wastes respectively. The latter includes also agro-industrial wastes.

The volume to be hauled can be calculated by the dividing the weight by the density of each type of waste.

For a hypothetical city of 100,000 inhabitants the quantities and volumes of each wastes with the exception of piped sewage are given in Table 15.

Assuming costs of U.S $0.50 per tonne mile and 4 miles average hauling distance, the total annual hauling cost per year is less than U.S. $450,000 for the total city wastes including solid, agro-industrial and animal wastes. This is less than 0.5 percent per year of the $100 million estimated total investment in sewage piped network which transports the liquid wastes.

Table 15. Total Hauled Wastes From a Model 100,000 Inhabitant City with Agricultural Fringes in Developing Countries

Types of Wastes	Population producing the wastes	Fraction of population	Daily Weight in kg per person or per animal	Daily Total Weight per city (tons)	Density tons per m^3	Daily Total Volume per city (m^3)
Night soil	30,000	0.30	1.2	36	1.05	34.3
Dry latrine	40,00	0.45?	0.25	10	1.2	8.3
Black water septage	20,000	0.20	14	280	1.02	274.5
Others (no facilities or piped sewage)	10,000	0.10	-	-	-	-
Solid wastes	100,000	1.00	0.52	52	0.43	121.0
Animal wastes:						
Cattle	3,000	-	18	54	0.95	56.8
Pigs	8,000	-	8	64	1.05	61.0
Chickens	100,000	-	0.05	5	0.70	7.1
Working animals	2,000	-	7	14	0.50	28.0
Organic industrial and agro-industrial wastes	-	-	-	70	1.00	70.0
Total				585		661.0

III. Non-Integrated Treatment Methods

Methods and processes of treatment or disposal which, whether in the authors' view are not recommended for developing countries, or do not offer an integrated solution to the various streams of wastes, or are lacking a significant resource recovery component are briefly described next. The principal reasons why they should be eliminated from consideration when selecting an integrated resource recovery system (IRRS) for developing countries are also given.

1. Liquid Wastes

"Conventional" Treatment Plants. The conventional treatment of municipal wastewater in Europe, North America and some highly developed parts of Asia (Japan, Singapore, etc.), Africa (mostly major cities in South Africa) as well as Australia and New Zealand (only in a few major cities) is composed of a train of processes as follows: (a) pretreatment composed of bar screens, communinators (occasionally), flowmeters, grit chambers and occasionally preparation; (b) primary treatment (physical) mostly composed of primary settling tanks with sludge scrapers and skimming of floatables; (c) a secondary biological treatment to remove suspended and dissolved biodegradable organic matter consisting of either activated sludge or (less often) trickling filter systems, both are followed with secondary settling tanks, and (d) sludge treatment facilities, for both the primary and the secondary sludges, composed of either anaerobic digesters (primary and secondary) followed by sludge drying beds, mechanical dewatering, followed by landfilling or incineration or occasionally sludge composting.

When quality requirements for the final effluent are more stringent, the above train of processes is supplemented by nitrogen removal processes (ammonia stripping or nitrification-denitrification), phosphorus removal (lime, alum, $FeCl_3$ or polyelectrolyte precipitation), granular activated carbon sorption and occasionally post-filtration (usually dual or multi-media) as well as disinfection (chlorination, ozonization or other methods).

The costs of such treatment as estimated by the EPA (1975) are given in Table 16.

A population of 100,000 in the U.S. needs a treatment plant of approximately 10 mgd while in developing countries the flow for such a population will range from 3 to 5 mgd with more concentrated raw sewage. It should be noted that the cost index from the 3rd quarter of 1974 to the 3rd quarter of 1981 is approximately 2.35 based on the inflationary increase of construction costs.

Therefore, the cost of primary-secondary activated sludge treatment operation and the overinflationary increase in energy will be over U.S. 60¢ per 1,000 short gallons or approximately U.S. $10 per person per year. The above calculations were based on favorable conditions of low interest rates that were valid in 1974.

The construction costs of activated sludge plants have been summarized by the EPA (1978) in Table 17.

Table 16. Component Costs for Wastewater Treatment Systems
(EPA 1975)
(costs in 3rd quarter 1974 dollars)

Process	Curve Designation [2]	Average flow, mgd					
		1	3	5	10	50	100
		U.S. ¢ per 1,000 gallons					
Basic Primary and Secondary Treatment							
Headworks	AA	2.7	1.4	1.1	0.8	0.6	0.4
Primary	A1	6.7	3.2	2.4	1.7	0.9	0.8
Activated sludge	C1	19.0	12.0	9.1	7.0	4.5	4.0
Disinfection	R	2.8	1.9	1.6	1.3	1.0	1.0
Sludge digestion	L1	4.1	1.9	1.6	1.3	1.0	1.0
Sludgy drying	O1	6.0	3.8	3.2	2.6	1.9	1.8
Sludge disposal	--	3.7	3.5	3.3	3.1	2.8	2.5
Administration	--	3.2	1.7	1.3	0.9	0.4	0.3
Subtotal		48.2	29.4	23.4	18.4	12.7	11.4
Advanced Treatment 1							
Nitrification	G2	11.0	6.8	5.6	4.5	3.2	2.8
Total		59.2	36.2	29.0	22.9	15.9	14.2
Advanced Treatment 2							
Nitrification	G2	11.0	6.8	5.6	4.5	3.2	2.8
Denitrification	H	9.4	6.2	5.3	4.4	3.6	3.6
Total		68.6	42.4	34.3	27.3	19.5	17.8
Advanced Treatment 3							
Lime addition	F2	12.0	6.0	4.8	3.4	1.8	1.5
Filtration	D	11.0	7.9	6.7	5.3	3.2	2.5
Sludge drying	O7	9.8	6.3	5.3	4.4	3.2	2.9
Recalcination	Q3	24.0	17.0	14.0	12.0	7.3	7.0
Incineration	P5-L1	6.7	3.8	2.9	2.0	1.0	0.8
Total		111.7	70.4	57.1	45.5	29.2	26.1
Advanced Treatment 4							
Ion exchange	I	14.0	11.0	9.8	8.5	6.5	5.9
Total		125.7	81.4	66.9	54.0	35.7	32.0

Table 17. Construction Cost Comparisons of Conventional Primary and Secondary Wastewater Treatment Plants (Costs in 2nd Quarter 1977 Dollars) (EPA 1978A)

(Secondary - Activated Sludge Plants)

PROCESS DESCRIPTION	1.0 MGD	10.0 MGD	20.0 MGD
Preliminary Treatment	U.S.$ 58,000	U.S.$ 856,000	U.S.$ 1,927,000
Influent Pumpint	147,000	771,000	3,216,000
Primary Sedimentation	69,000	761,000	1,565,000
Activated Sludge (1)	227,000	1,683,000	3,076,000
Secondary Clarification	109,000	1,115,000	2,246,000
Effluent Chlorination	53,000	492,000	963,000
Effluent Outfall	74,000	1,732,000	4,478,000
Gravity Thickening	33,000	413,000	885,000
Aerobic Digestion	147,000	2,029,000	4,472,000
Other Sludge Handling	43,000	976,000	2,205,000
Mechanical Dewatering	34,000	1,401,000	4,278,000
Landfill of Sludge	(No Capital Cost)	(No Capital Cost)	(No Capital Cost)
Control/lab. Main. Bldg.	165,000	1,728,000	3,504,000
Cost of Unit Processes	1,159,000	13,957,000	32,815,000
Mobilization	48,000	674,000	1,495,000
Sitework	112,000	1,045,000	2,047,000
Excavation	138,000	1,421,000	2,523,000
Electrical	136,000	1,360,000	2,720,000
Controls & Instrumentation	51,000	667,000	1,450,000
Yard Piping	100,000	1,067,000	2,179,000
HVAC	31,000	539,000	1,272,000
Total Cons. Component Cost	616,000	6,773,000	13,686,000
Total Plant	$1,775,000	$20,730,000	$46,501,000

(1) Included in Process Cost are equipment, concrete, steel and interprocessing pumping.

Due to the more concentrated raw sewage typical of developing countries the costs of a treatment plant with 8 mgd capacity should apply to a city of 100,000 inhabitants although the nominal flow will probably be less than 5 mgd.

With a cost increase index of approximately 1.55 between the 2nd quarter of 1977 to the 3rd quarter of 1981, such a treatment plant in the U.S. would cost approximately U.S. $28 million for a city of 100,000 or approximately U.S. $280 per person. If we assume a very conservative 20 years longevity of the entire plant and a current 8.0 percent interest (which is applicable only for tax-free municipal bonds), the capital recovery alone would be $26.43 per person per year which will bring the total costs of treatment (including operation and maintenance) to approximately U.S. $35 per person per year.

The above calculations were made on the basis of costs in the U.S. In developing countries the costs of labor is significantly lower but the cost of equipment and energy can be appreciably higher.

The conventional wastewater treatments discussed above carry some elements of resource recovery, particularly in the use of the final effluent for irrigation as well as the use of dried digested sludge as a fertilizer or the use of partly dewatered raw sludge for composting. The energy recovery from anaerobic digestion of sludge (via biogas production) can be used to cover a part of the energy requirement within the treatment plant itself, particularly when an energy-intensive process such as activated sludge is used.

The major reasons why conventional treatment is not recommended by the authors for conditions of most developing countries are summarized as follows:

1. High construction and operation and maintenance costs.

2. The need of highly skilled operators.

3. High energy requirements for aeration, recirculation pumping and sludge dewatering (in case of mechanical sludge treatment).

4. The system cannot be used as an integrated solution for other wastes such as solid wastes and animal wastes (with the exception of the sludge that can be combined with other wastes using anaerobic digestion or composting.

5. Resource recovery is limited to utilization of the water for irrigation and the sludge as a fertilizer but cannot serve as a major recovery system of energy or nutrients.

6. The conventional treatment process is efficient only with relatively diluted wastewater and is therefore limited to conditons of cities with fully piped sewerage. The overall retention time of the liquid phase is between 9 to 15 hours, thus the removal of bacterial pathogens is only by 2-3 orders of magnitude (as indicated by the removal of indicator coliform bacteria) and even less efficient in removal of viruses. The addition of disinfection is therefore essential but operational reasons in developing countries might reduce its application or its effectiveness.

8. Standard-rate conventional biological systems (activated sludge or trickling filters) produce effluent with a high ammonic content which might be toxic to fish and other aquatic fauna in receiving bodies of water, in recreational lakes or in any fish and aquaculture usages.

Due to the low area requirements of conventional treatment, it might still be justified in communities in developing countries where land is extremely limited. These conditions are rare, however, in most developing countries, particularly in medium-size townships.

Stabilization Ponds. A series of stabilization ponds which include anaerobic, facultative and aerobic ponds constitute an excellent solution under the conditions of most developing countries. They do not provide,

however, an integrated solution to other types of wastes. A modified design that does provide for an integrated solution incorporating solid and animal wastes is discussed later in more detail under the title "Stabilization Ponds - Anaerobic Digestion Combies."

High Rate Ponds. The high-rate ponds, composed of mixed, shallow meandering channels, where conditions favor maximum algal biomass production, constitute an excellent solution for the liquid wastes of developing countries. Both the water and the nutrients (the latter is proteinaceous animal feedstuff) are recovered while energy requirements are minimal. Area requirements are only less than one tenth of those needed for a series of stabilization ponds. Since they do not constitute an integrated solution to solid and animal wastes they will not be discussed. A modified design which does incorporate solid and animal wastes will be discussed under the title "High Rate Algal Ponds - Anaerobic Digestion Combies."

Aerated Lagoons. Earth lagoons (sometimes with a minimal lining) aerated by floating surface aerators can provide a solution to municipal liquid wastes in developing countries. Their advantage over conventional primary-secondary treatment is reduced construction costs and simpler operation and maintenance. The final effluent expected from such treatment is appreciably inferior to conventional biological treatment. Their major drawbacks are the high electrical energy requirements for aeration, the absence of any recovery component (not even sludge) except for the use of the final effluent for irrigation of restricted crops and their inability to offer an integrated solution with solid and animal wastes.

2. Solid Wastes

Sanitary Landfilling (Tipping). This method is best recommended for disposal of municipal solid wastes but is practically lacking any element of resource recovery and does not offer an integrated solution with liquid wastes. It can also cause pollution of ground and surface waters. In a few instances a certain amount of biogas can be recovered from sanitary landfills, this is feasible only in the larger size cities with old and deep landfills that have been operating for a few years. Moreover, only a fraction of the potential production of biogas is realized.

Composting. Composting will be discussed in a later section as an integrated solution for solid wastes, sludges and animal wastes.

Incineration. Incineration of solid wastes as a method for disposal and energy recovery (hot water, steam or electricity) has become popular in Western Europe, Japan and the U.S.A since the early sixties and even more so since the "energy crunch" in the seventies. Methods include waterwall mass combustion, refuse derived fuel (RDF), modular incinerators and dedicated incinerators.

The minimum calorific value for incineration to be considered economical is about 1,600 Kcal/kg of wet solid wastes. As indicated in previous chapters, the calorific value of typical refuse in developing countries is less than 1,000 Kcal/kg. Although a slow trend of increasing calorific value (with the use of more paper and plastic material) and decreasing moisture content has been recently observed, it is still thought that incineration will not provide the answer to most developing countries in the coming decades.

As shown in Table 18, the net cost of incineration even in the U.S. (where the calorific value ranges from 2,500 to 3,500 Kcal/kg) is above $8 per short ton for large waterwall incinerators and approximately $16 per ton for RDF (accounting for both the value of the energy and the front-end recovered material).

A recent report by Cointreau (1982) published by the World Bank provides a general statement of the planning needs for urban solid wastes in developing countries. The report spells out in considerable detail how data should be collected to prepare solid waste projects for consideration for funding by external funding agencies.

Table 18. Comparative Cost Estimates of Various Refuse Treatment and Disposal Systems (19) with Capacity of 1,000 Tons per Day (Costs Based on U.S. Data February 1980).

	Capital Investment[1]	Cost per ton refuse			Resource Value (revenue) per ton refuse			Net Cost
	million U.S. $	Capital $/ton	O & M $/ton	Total $/ton	Energy $/ton	Material $/ton	Total $/ton	$/ton
ndfilling[2]	3.5	1.40	5.60	7.00	-	-	-	7.00
ndfilling[3] ong haul)	3.5	1.40	10.20	11.60	-	-	-	11.60
terwall Incineration[4] ack-end full recovery)	55.0	14.40	20.00	34.40	24.00	2.00	26.00	8.40
F-Dedicated Boilers[4] ront-end full recovery)	60.0	15.70	30.00	45.70	24.00	8.00	32.00	13.70
mposting lly mechanized)	30.0	8.00	15.00	23.00	-	12.00	12.00	11.00
mposting nduced air wind-rows)	8.0	2.10	17.00	19.10	-	11.00	11.00	8.10
olysis	52.0	13.60	28.00	41.60	18.00	6.00	24.00	17.60

sed on 7 percent interest and amortization over 20 year period except for ere amortization is over a 10 year period.

sed on refuse transportation (haul) equal in distance to other alternatives; no lowance for possible biogas recovery.

sed on extra transportation distance of 25 miles; no allowance for possible biogas covery.

sed on 6,000 lbs of steam per ton of refuse @ $4.000 per 1,000 lbs.

rce: Shelef (1981)

IV. Survey of Integrated Resource Recovery System Components Review

A. Survey of Component Processes

1. Introduction

This section discusses the major component processes of integrated resource recovery systems that would be well-suited for implementation in India and elsewhere in warm-climate developing countries. The first half of the chapter reviews briefly the components themselves while the second half surveys IRR systems presently in operation. A short discussion of the microbial ecology that lies at the heart of methane generation and waste stabilization ponds is also included.

2. Waste Stabilization Ponds

Also known as oxidation ponds, stabilization lagoons and maturation ponds, waste stabilization ponds are large shallow ponds that provide an adequate environment for the biological transformation of complex organic materials to mineralized matter, simple organic compounds and biomass. The relative ease and low cost of construction, maintenance and operation make them particularly appealing for wastewater treatment in developing countries.

Waste stabilization ponds are classified into three general types, according to the type of biota which they support: anaerobic, facultative and aerobic. Anaerobic ponds sponsor the growth of facultative and anaerobic bacterial fermenters (facultative organisms have two or more sets of enzyme systems that enable them to survive and grow in both anaerobic and aerobic environments), which can be broadly divided into two

important groups: the organic heterotrophs and the methanogens (methane-forming bacteria).

The fermentation and hydrolysis of proteins, lipids, carbohydrates, and other complex organic compounds to methane, the most reduced carbon compound, by these two groups is now thought to be a multi-step process (Zehnder, 1978) but the biochemistry is still largely unknown. One set of organic heterotrophs hydrolyze and ferment the complex compounds to fatty acids, alcohols, CO_2, ammonia, and molecular hydrogen while another set converts these intermediate products into acetic acid, more hydrogen and CO_2 (Zehnder, 1978) These products reduce the pH of the wastewater if allowed to accumulate, but the utilization of the hydrogen by the methanogens to produce CH_4 helps stabilize the system. If the acid-fermentation products are produced at a rate greater than the hydrogen utilization rate of the methanogens the system becomes poisoned and methane production ceases, since the methane-producing organisms require a nearly neutral pH for optimal growth. In addition, the organic heterotrophs consist of a wide variety of microbial organisms and are generally able to withstand a wide-range of environmental conditions. The methanogens are far more sensitive to variations in their environment and they are extremely oxygen sensitive. The end-result of this multi-step process is the loss of carbon from the waste stream through the evolution of methane gas.

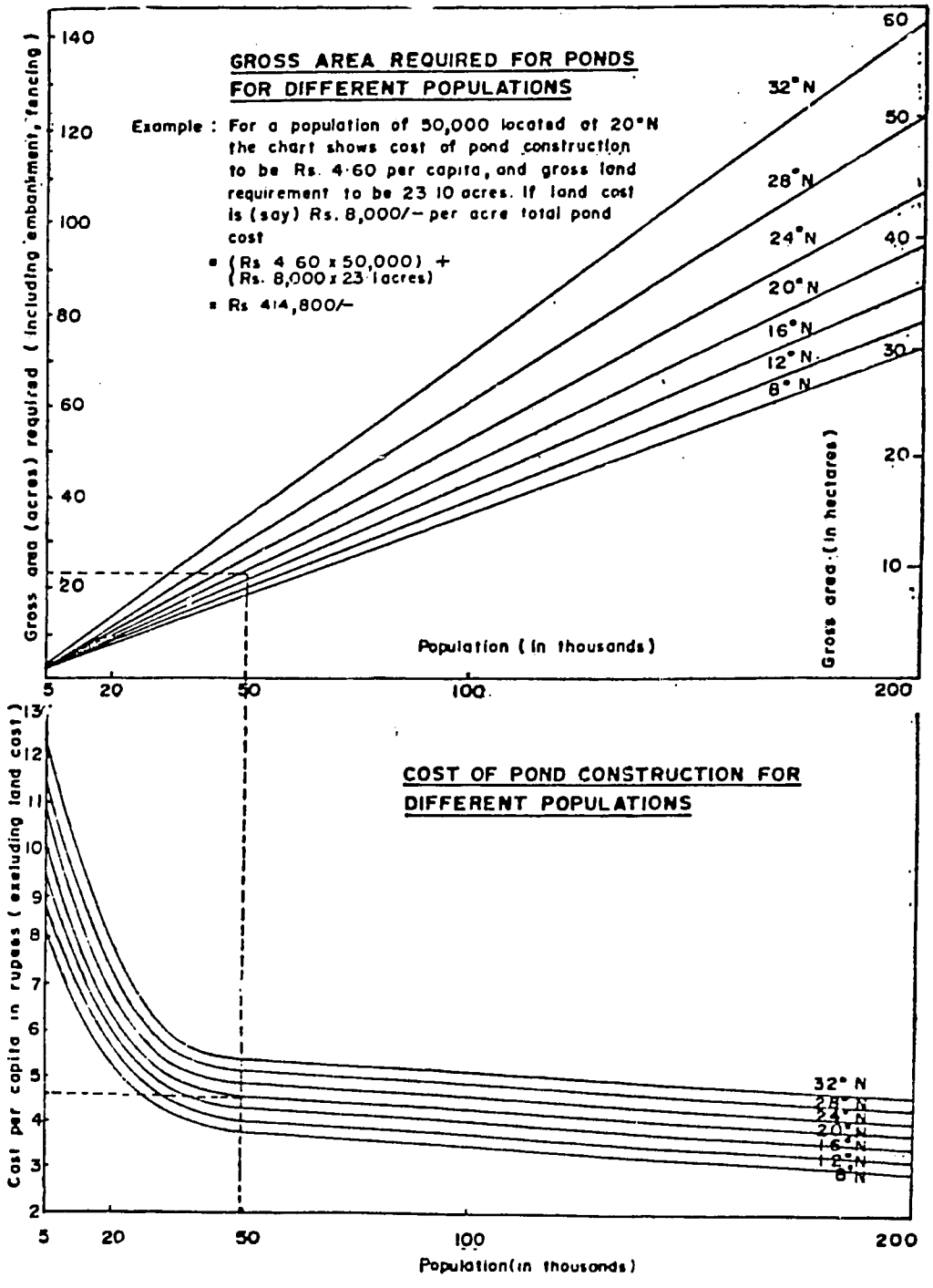
In an aerobic system, organic heterotrophic bacteria are also the agents responsible for degrading the complex organics (although they are aerobic), but instead of anaerobic fermentation taking up the intermediate products, the mineralized matter is utilized by green algae and

cyanobacteria (blue-green bacteria, often misnamed "blue-green algae") to produce more biomass. Thus, carbon from the waste material is transformed into algal biomass. A facultative pond is one where the bottom waters are anaerobic and the upper layers are aerobic through most of the day.

An anaerobic pond is usually deeper (about 5 feet or 1.5 m in depth) than an aerobic pond in order that the water nearest the bottom sediments does not become oxygenated. An aerobic pond, however, is best situated where wind-induced mixing is maximized and the pond is shallower, approximately 3 feet. Residence times and loading rates are different for these two types of ponds and, as will be presented in the next chapter, are often best arranged in series.

Operation and maintenance requirements are relatively minimal, but must be kep up regularly in order to prevent mosquito breeding or nuisance odors (Arceivala et al., 1970); aquatic weed growth in and around the pond must be prevented, especially. Both aerobic and anaerobic pond performances improve when the average temperature is relatively high and constant, as is southern India. Construction and land costs form the greatest part of capital costs and so it is obvious that waste stabilization ponds are more cost-effective when land prices are not at a premium. Figure 7 shows some costing information for aerobic ponds in India in 1970.

Figure 7. Gross Area Required for Ponds for Different Populations



Source: Arceivala et al., 1970.

3. Biogas Plants

Principles of Biogas Production. The anaerobic digestion of organic wastes produces via fermentation reactions an end product mixture of methane (50-70 percent) and carbon dioxide, with some hydrogen sulfide and traces of other gases. Methane, which has a calorific value between 4 and 5 kcal/liter, imparts combustability to the gas (also known as biogas, gobar gas, swamp gas) making it suitable for domestic and industrial applications. Methods for purifying the biogas to eliminate the H_2O and CO_2 are well-established and relatively inexpensive (typically with 'iron sponge' - woodchips and Fe_2O_3 sponge - Sood, 1980) but not essential since there are reliable applications for unpurified biogas (Barnett, 1978). Removal of H_2S eliminates odor; removal of CO_2 improves the combustion quality of the gas (i.e., its calorific value and flame temperature). Many factors affect the digestion process, rate of gas production and yield (percent methane). These variables, and the possiblity of using them as a control variable are given in Table 19. Table 20 shows the most significant measurable variables which indicate digester behavior.

Chemical Factors. Methane producing bacteria are highly sensitve to temperature and operate most efficiently around 35°C (95°F) in the mesophilic range (Eusebio and Rabino, 1978). Initially, the pH in a digester is low; however, as digestion continues, the pH rises. Methane production peaks at a pH value between 7.5 and 8.0 (Eusebio and Rabino, 1978).

Table 19. Inputs and Disturbances of Digestion Process

Parameter	Easily Measurable?	Possible Control Variable
BOD, COD feed	No	No
Feed composition	Difficult	Yes[1]
Feed: physical state, size	No	No
Feed concentration (solid:liquid)	Yes: approximately	Yes[2]
Retention time	Yes	Yes[2]
Loading rate	Possible[3]	Yes[2]
Bacterial, or seed content	No	Yes[4]
Feed temperature	Yes	Yes[5]
Toxic materials	No	No
Nutrient content	No	Yes[6]
C/N ratio	No (but calculable)	No
Heat input	Indirectly	Yes
Heat losses	No	No
Pressure	Yes	?[7]
Ambient temperature/conditions	Impractical	No
'Secondary' disturbances[8]		
Gas composition		?
Digester temperature		--

Note: A rather subjective opinion has been taken as to what is 'easily' or 'cheaply' measurable. The categories are thus extremely subjective and inexact.

[1]By adding lime, urea, etc. to control pH or stimulate the operation.

[2]Little is known of the dynamic effects of (small) changes in these variables, which are, of course, interrelated.

[3]Dry solids could probably be measured relatively frequently but monitoring of loading rate is impractical in rural application.

[4]By using 'starters' or recycles - again, there is little experience to draw on.

[5]At some cost.

[6]By adding known quantities of specified nutrients.

[7]Effect as yet unexplored.

[8]These are really 'state' (i.e., dependent variables) which themselves can affect further behavior.

Source: Barnett, 1978

Table 20. The Most Significant Measurable Variables that Reflect (and Influence) Digester Behavior

Variable	Easily (cheaply) Measurable?	Recommended Acceptable Range	Measurement Technique
Temperature	Yes	10 - 60° C	Thermometer etc.
pH	?	6.4 - 7.5 (8.0)	pH meter: litmus
E_h	No	-330 mV redox pot.	Instrument
Alkalinity	?	2000 - 35000 mg/litre ($CaCO_3$)	Titration
Toxic materials technique	No	depends on species	Specific
Gas production rate	?	--	Meter
Gas composition	?	50 percent CH_4	Orsat analysis
Nutrient levels	No	depends on nutrient	--
BOD, COD analysis regulation)	No (?)	(Variable + depends	Laborious on water
Cell content	No	-- (higher the better?)	--
Bacterial population	No	--	--

Note: A rather subjective opinion has been taken as to what is 'easily' or 'cheaply' measured. The categories are thus extremely subjective and inexact.

The variables noted with a question mark are ones that can be measured relatively easily, but may not yet be feasible within the context of village technology.

Source: Barnett, 1978

Gas production varies seasonally. Since the production of gas falls off dramatically at lower temperatures, a substantial amount of research has focused on insulation and heating of biogas plants. 300 percent production increases have been recorded in India with the use of underground external water jackets and insulation with agricultural wastes (Sood, 1978). This work is crucial because 70 percent of Indian biogas plants are located in northern India where the mean winter temperature is 12°C. Gas production for the whole country varies from .093 cu.m/kg during summer (mean temperature of 30°C) and .038 cu. m/kg during winter (mean temperature of 15°C).

Input Composition Factors. Digester inputs can be either batch or continuous, the modes of operation are determined by the digester design which will be discussed subsequently. A large percentage of digesters are built for continuous operation. Evidence for the relative efficiency of these two modes of operation is controversial; however, it is claimed that the continuous mode is more efficient (i.e., has higher gas production-rates per unit digester volume) (Barnett, 1978). A disadvantage to this system as pointed out by Barnett is that it requires daily attention to maintain steady operation conditions whereas the batch process is self-sufficient for periods of 60-90 days (total time for complete digestion). The continuous processes are generally more sensitive to operating parameters for this reason, batch processes are well suited to the treatment of straw-type and fibrous material, especially if previous homogenization is not possible or uneconomical.

Feeder composition is probably one of the factors which has been most often varied. In practice, heterogeneous residual stream inputs are

widespread while homogeneous streams are restricted to laboratory settings, pilot-plants or plants established for specific agricultural or industrial processors/producers. Materials used for input into the digesters include: carbon sources - leaves, grass, agricultural wastes; nitrogen sources - human and animal wastes. Experience with Indian Gobar plants using a mixture of unprepared rice straw with the manure results in a dramatic decrease of gas production indicating the plant's inability to digest fibrous material, typically farm wastes. This characteristic has stimulated further experiments. In Berlin, for example, straw is rotted and/or cut as preparation for the batch system, which clearly enlarges the need for trained manpower. On the other hand, Chinese experience has indicated various operational combinations of raw material. As an example, FAO (1978) gives the following mixtures as suitable for biogas plant: 20 percent urine, 30 percent human excreta, and 50 percent water; 10 percent human excreta, 30 percent animal dung, 10 percent straw and grass, and 50 percent water; or 20 percent human excreta, 30 percent pig manure and urine, and 50 percent water; or 10 percent each of human and animal waste, 30 percent marsh grass, and 50 percent water. What is of major importance is that crop wastes, green grass, and other vegetable materials are decomposed for more than 10 days prior to being put into the digester.

The principle consideration in determining feeder composition is the carbon:nitrogen ratio. Optimal C:N ratios should be in the range of 10:30 to 20:25 (Kalbermatten et al., 1980); an imbalance of either element causes inefficient or termination of digestion. Typical C:N ratios of various inputs are given in Table 21. Relative efficiencies of gas production for selected sources are shown in Table 22. Night soil

Table 21. Typical Carbon/Nitrogen Ratios of Some Feeds

	N (percent dry weight)	C/N ratio
Night soil	6	6-10
Cow manure	1.7	18
Chicken manure	6.3	7.3
Horse manure	2.3	25
Hay, grass	4	12
Hay, alfalfa	2.8	17
Seaweed	1.9	79
Oat straw	1.1	48
Wheat straw	0.5	150
Bagasse	0.3	150
Sawdust	0.1	200-500

Source: Barnett, 1978

Table 22. Comparative Efficiency of Various Types of Wastes for Gas Production

Cow dung	100.0
Water hyacinth	114.0
Sorghum residue	130.0
Water lettuce	145.0
Pig manure	154.0
Grasses	177.0
Rice straw	187.0
Night soil	221.0

Source: FAO, 1978

generally lies in the 6:10 range, thus, the addition of carbonaceous materials (typically agricultural wastes, grasses, leaves, straw) is required to maximize efficiency of production. Cow dung, for which many biogas units are designed, has a nearly ideal C:N ratio of 18:25, usually small quantities of night soil will have a negligible effect on units operating on cow dung (Kalbermatten, 1980). Typical and maximum yields based on different input sources are shown in Tables 23 and 24.

Dilution Rate. Dilution rates vary widely, however 9-10 percent solids concentration (i.e., a 1:1 dilution:feeder input) is typical. Water requirements essentially depend on two factors: the solids concentraton of the input stream and the hydraulic retention time (Barnett, 1978). Higher solids concentrations are advantageous in that they reduce the required digester volume, however, problems with handling of solid slurry and toxic ammonium buildup have occurred under these circumstances.

Loading Rate and Retention Time. Much investigation has focused on varying loading rates and retention times and corresponding gas production rates (Barnett, 1978; Kalbermatten et al., 1980 and Rybczynski et al., 1978). The results indicate that process design of biogas plants is empirical.

The Israeli work on anaerobic digestion has concentrated on setting up a continuous process with as high a concentration of organic material as possible in the digester (Marchaim, 1977). In order to increase the gas volume, the solids concentration has been increased from the normal U.S. 8-10 percent to 18 percent, and the retention time has been decreased from

Table 23. Typical Reported Yields from Anaerobic Digesters

	Gas yield (m^3/kg volatile matter fed)	Gas composition (percent methane)
Cow dung	0.90-0.3	65
Chicken manure	0.3	60
Pig manure	0.35-0.48	65-70
Farm wastes	0.3-0.42	60-70
Elephant grass	0.42-0.54	60
Chicken manure/ paper pulp	0.42-0.48	60
Chicken manure/ grass clippings	0.35	68
Sewage sludge	0.6	68

Source: Barnett, 1978

Table 24. Maximum Gas Yields (From Various Sources)

	N	C/N	C%	Gas yield (ft^3/lb DM)
Feces	-	-	40-55	22.4-30.9
Blood	10-14	3	30	16.8-23.5
Young grass clippings	4	12	48	26.9
Lucerne	2.4-3	16-20	60	33.5
Grass clippings	2.4	19	45.6	26.5
Manure (large)	2.15	14	30.1	16.86
Seaweed	1.9	79	36.1	20.2
Oat straw	1.05	48	50.4	28.2
Wheat straw	0.3	138	38.4	21.5
Sawdust	0.11	511	56.2	31.5
Carbohydrate	-	-	-	12.0
Fat	-	-	-	23.1
Protein	-	-	-	15.7
Horse manure	2.3	25	57.5	32.2
Cow manure	1.7	18	30.1	17.22
Hay	4	12	48	26.9
Pig manure	3.8	20	76.0	42.5
Sheep manure	3.8	22	83.6	46.7
Poultry	6.5	15	90	50.3
Garbage	3	-	54.7	30.5
Paper	-	-	40.6	22.8
Newspaper	0.05	-	40.6	22.8
Chicken manure	3.2	-	23.4	13.2
Steer manure	1.35	-	34.1	19.1

Note: To convert ft^3/lb to m^3/kg multiply by 0.62.
Source: Barnett, 1978

8 days (about 1/8 of the volume of slurry in the digester is replaced daily) to 6 days. Retention times currently in use in Asia are in the range of 25 to 30 days. The daily production of about 1 volume of biogas has been increased to 4-5 volumes of biogas per 1 working volume of digester (on a pilot scale). Mixtures of raw material have ranged from manure alone to over various crop-manure mixtures to only cotton stalks. The Israelis found that the most likely prospect for an efficient system is a combination of crop waste with manure. If it becomes feasible to obtain large, suitable systems for producing gas at 5 or more times the volume of the digester, it will be possible to send a steady flow of biogas to installations requiring continuous operation. In this case then, storage systems will become necessary, particularly in places where the demand for energy is not constant, which explains why the problem of compressing the biogas has also been studied.

Generally, loading rates range from 0.5 to 3.0 kg of volatile solids/m^3 of digester volume per day (Kalbermatten, 1980)*. Retention times from 5 to 30 or more days are typical. Production rates with varying input mixutes, dilution rates and retention times under mesophilic conditions are given in Table 25. Dung from one cow or similar animal can produce 500 liters of gas per day whereas human excreta yields only 30 liters per person daily. In general, gas production from a continuous or semi-continuous operation is approximately one third to one half the digester volume per day.

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*Equivalent to approximately 60-40 kg cow dung (wet weight) or 14-66 kg night soil (net weight) per m^3 per day.

Table 25. Rate of Gas Production from Different Mixtures of Wastes at 25-28°C

Materials	Mixture Proportion	Gas production after 70 days per gramme of material (ml)	Gas production after 400 days per gramme of material (ml)
Grasses)	3:1	178	-
+)	1:1	152	-
rice straw)	1:2	184	-
Rice straw	-	120	240
Human excreta) +) rice straw)	1:4	-	384
Wheat straw	-	-	160
Human excreta) +) wheat straw)	1:4	-	316

Source: FAO, 1978

Research has indicated that increases in efficiency of digestion occur when the input feed is "seeded" with previously digested slurry from the output tank. This procedure acts as a start-up culture for the bacterial populations required for digestion (Eusebio and Rabino, 1978).

Effects of seeding are indicated in Table 26. Another activity which increases digestion efficiency is stirring. In continuous mode operations, some mixing occurs with each additional input making a manual or mechanical stirrer (as occurs in Japanese design plants) unnecessary. Mixing the digester material serves to decrease stratification, increase the contact between bacteria and substrate, break up surface scum and possibly increase decomposition rate (Barnett, 1978).

Design Factors. Biogas plant designs in India have predominantly been units containing an expensive steel gas holder (30-40 percent of the cost). This model is subject to corrosion and maintenance problems and an alternative design with a ferro-cement gas holder has proven to be inferior in strength and flexibility. Other materials and combinations are currently being investigated. The Chinese design biogas digester with a single unit, dome-shaped, brick and masonry gas holder situated underground is becoming more popular. Drawbacks of the latter design include: lack of mechanism to break scum, manual labor required for pumping slurry from outlet chamber, and fluctuations of gas-pressure. KVIC and the Ministry of Agriculture and Irrigation are successfully experimenting with modifications of the Chinese design (Sood, 1978).

Detailed comparison of the diverse digester designs is beyond the scope of this report. Fundamental differences in design result from different objectives or priorities, for instance, batch versus continuous

Table 26. Effect of Seeding or Innoculation of Fresh Material with Digested Material

Fresh Material	Digested slurry (g)	Gas production (ml/g of material)
250 g night soil	20	27
" "	100	138
" "	400	307

The above established the beneficial effect of 'seeding' the fresh material with digested slurry which acts as an inoculum.

Source: FAO, 1978

design, maximum treatment of wastes versus maximum generation of methane. Another important factor is local expertise, materials available and ambient environmental conditions. A comprehensive summary of the main design variants and comparative performance is given in Table 27. There are relatively few problems of research and development nature associated with storage and landing of the biogas. Dangers and limitations are well documented (Barnett, 1978). Owing to the low pressure and low flame propagation speed of biogas, special designs are required for storage and efficient appliance/engine use. Further research and development is needed as much of the available findings are inconsistent.

Biogas Product Use/Quality. The calorific value of biogas compares favorably with other fuels typically used in Southeast Asia (see Table 28); in addition biogas is cleaner than these fuels. Multiple uses of the gas, which is quite similar to natural gas, are common in most countries; domestic cooking, lighting and pumping irrigation water are the major uses. The rates and quantity of gas utilized for different purposes is shown in Table 29. Quantity required varies widely depending on the efficiency of the appliance used. As mentioned previously, many of the appliances including simple burners and lights make inefficient use of biogas.

An important product in biogas production, overlooked in some countries while more important than the methane gas generated in countries such as China is the digested slurry (or sludge and effluent). This is a crucial resource recovered through biogas plants, particularly in areas where soil fertility is dwindling, water for irrigation is scarce and crop productivity must be increased to support increasing populations.

Table 27. Summary of Operating Conditions of a Range of Different Digester Designs

Name of plant	Rated capacity	No. of stages	Digester size Vol. I	Vol. II	Total Vol.	Temp (°C)	Cows No. (Qty)	Pigs No. (Qty)	Chickens No. (Qty)	Other No. (Qty)	Vegetable Qty	Total Qty	Dry Solids	Vol. Matter	Water	% solids (dry)	Loading rate	Gas product (daily)	BOD In	BOD out	VS In	VS Out	Residence Time	Comments	Reference
CHAN TINE		1	54 ft^3	-	54 ft^3	36 no control		1,000 lb/d					65 lb/d	52.5 lb/d		6.5%	0.97 lb VS/ft^3/d	130ft^3			25% destruction	1-4 days		Calculated	--
CHAN TINE		1 plus lagoon	1,000 l + 1,000 l sed.	- -	3,000 l	35 no control		230 kg/d				230kg/d			10:1		7 kg/m^3/d	300 kg - 15000 l day		no data			1 day	Design data	Richard
D.C.S. SEPAL	180 ft^3 (winter)	1	8.5m^3	-		25	5(45 kg/d)	-	-		-	45 kg/d	18%	6.75 kg/d	1:1	7-9%	0.8 kg/m^3/d	100 ft^3 (3m^3)		no data			approx 60 days	Design data	Finley (1976)
D.C.S. SEPAL	180 ft^3 max	1	8.5m^3	-	8.5m^3	about 30	7/W (60 kg/d)	-	-	-	-	60 kg/d	18%	10 kg/d	1:1	7-9%	1.2 kg/m^3/d	180 ft^3 (5m^3)		no data			approx 30 days	Design data	Finley (1976)
FISHER	100 ft^3	1	100 ft^3			30	4					40 kg/d	18%	5 kg/d	1:1 (?)	7-9%	0.6 kg/m^3/d	100 ft^3 (claimed)	no data				no data approx 30 days*	Design claim	Fisher (1972)
FRI	3,000 ft^3					30 + control	130 cows or 800 pigs					1100-2600 kg/d	18% max	200-400 kg/d	?	8%	6 kg/m^3/d	3000 ft^3	no data				30 days*	Design claim	Wright Rain (1981)
[illegible]	4m^3	1	7m^3	-	7m^3	30-35	8 (80 kg/d)	-	-	5 people	-	85 kg/d	10-20%			8%		4m^3/d	no data				42 days		Florida (1974)
[illegible]	?	1	5.5m^3	-	5.5m^3	24	6 approx (60 kg/d)	-	-	-	Straw	100 kg/d (fresh)	20% +		no data		3 kg/m^3/d	2m^3/d (3.3m^3/d at 35°C)	no data				30 days	Tentative figures	
LAPP	?	2	185m^3	?	185m^3	no data	-	1,000 (3,000 kg/d)				1000 kg/d	no data	14%	no data		2.4 kg/m^3/d	30m^3/d					30 days		Lapp (1974)
LAPP	?	2	5.6m^3	?	5.6m^3	35	-	no data				-	-	14%	no data		1.6 kg/m^3/d	4m^3/d?					20 days		Lapp (1974)
MANN	?	1	465 ft^3	-	465 ft^3	no data	——— mixed feed ———					300 ft^3	no data	no data	no data	no data	no data	1/1 digester volume/day					50-70 days	darin	Mann (1942)

Continued on following page

Table 27. Summary of Operating Conditions of a Range of Different Digester Designs (cont)

Name of plant	Rated capacity	No. of stages	Digester size Vol. I	Vol. II	Total Vol.	Temp (°C)	Cows No. (Qty)	Pigs No. (Qty)	Chickens No. (Qty)	Other No. (Qty)	Vegetable Qty	Total Qty	Dry Solids	Wet Matter	Water	% solids (dry)	Loading rate	Gas product (daily)	BOD In	BOD out	VS In	VS Out	Residence time	Comments	Reference
MAFA Farm	-	1.32X batch	600m³ total		60m³	?	-	5,000 (6-8 cum/d)				no data						Approx 100,m³/d (1/3 vol/day)		no data			Batch cycle	LET/Bm/(2) ?	Ulzes
SEKHI	-	1	230 ft³	-	6.5m³	19.7 14.1 16.4 16.1	water temp.			night-soil digester							0.104 kg/m³/d 0.076 kg/m³/d 0.096 kg/m³/d 0.086 kg/m³/d	1.2 1.6 (volumes 1.3 per day) 1.4					24 22 26 28	Trade-off effect	Sathianathan
SEKHI		1	1m³		1m³	?	no data					8.0 kg/d 16.0 kg/d 24.0 kg/d 32/0 kg/d					1.17 kg/m³/d 2.4 kg/m³/d 3.8 kg/m³/d 5.1 kg/m³/d	0.22 0.42 (volumes 0.52 per day) 0.47					53 25 17 12	Trade-off effect	Sathianathan
PATEL	100 ft³	1	110 ft³ (approx 3m³)			meso-philic	4-5					50 kg/d	18%		1:1		2.5 kg/m³/d	104 ft³ nominal					25-30 days		"Biogas"
PATEL	300 ft³	1	approx 9m³			meso-philic	12/15					120-170 kg/d	18%		1:1		2.5 kg/m³/d	300 ft³ nominal					25-30 days		"Biogas"
[illegible]	-	2			18,000 ft³ 30,000 ft³	30	280 280	(or equivalent)			no data (straw)	30 kg/d Total X 250		800 kg/d	?		0.105 lb/ft³/d 0.0625 lb/ft³/d	18000 ft³ 14000 ft³							Sathianathan
[illegible]	-	2			15,000 ft³	35-40	130										0.06 lb/ft³/d	17300 ft³						strong temp. effect	Sathianathan
SINGH	various	see various papers by Singh														7-9%	5 lb/ft³/d	Claims 1/2 to 1 volume per day					30-60 days		Singh (1971)
Taiwan	3.5m³	1	5.4m³	-	5.4m³	30(?)	-	10-15 hogs plus water (17 kg/d)				17.4 kg/d	30% T.S.	4.25 kg/d			0.8 kg/m³/d	0.825 m³/day		about 64% reduction			6 days	See Paper	Chung Po (1974)
Taiwan	3.5m³	1	5.4m³	-	5.4m³	30(?)	-	10-15 hogs plus water (17 kg/d)				17.4 kg/d		4.25 kg/d			0.18 kg/m³/d	2.3 m³/day		about 68% reduction			8 days	See Paper	Chung Po (1974)
Taiwan	3.5m³	1	5.4m³	-	5.4m³	30(?)	-	10-15 hogs plus water (17 kg/d)				17.4 kg/d		4.25 kg/d			0.8 kg/m³/d	3.5 m³/day		about 68% reduction			10 days	See Paper	Chung Po (1974)

(1ft³) = 0.028m³, to convert lb/ft³/day to kg/m³/day multiply by 16.02).

Source: Barnett, 1978

Table 28. The Effective Calorific Value of Biogas Compared with Some Other Fuels

$1m^3$ of biogas will generate approximately 23×10^6J (5500 kcal) of heat energy.

Fuel	Calorific value
Biogas	15,600 kJ kg^{-1}
Wood	2,400 kJ kg^{-1}
Charcoal	7,000 kJ kg^{-1}
Kerosene	18,000 kJ kg^{-1}

Source: FAO, 1978

Table 29. Uses of Methane and Requirements (from Sathianathan 1975)

Use	Quantity (m^3)	Rate
Cooking	0.32	5-cm diam. burner/h
	0.46	10-cm diam. burner/h
	0.63	15-cm diam. burner/h
	0.28-0.42	per person/day
	0.07	boiling water/litre
Lighting	0.07-0.08	1 mantle lamp/h
	0.14	2 mantle lamps/h
	0.17	3 mantle lamps/h
Refrigerator	1.07	flame operated m^3/h per m^3 refrigerated space
Incubator	0.36-0.71	mk^3/h per m^3 incubator space
Gasoline engine[1]		
CH_4	0.42	per kW/h
Biogas	0.60	per kW/h
Equivalent to:		
(a) Gasoline		
CH_4	1.00-1.18	per litre
Biogas	1.33-1.85	per litre
(b) Diesel oil		
CH_4	1.11-1.39	per litre
Biogas	1.48-2.06	per litre

[1]at 25% efficiency.

Source: Barnett, 1978.

Rate and amounts of effluent produced are dependent on digester design and operating conditions. Sludge outputs per year are roughly equivalent to the digester capacity (e.g., a 10 cubic meter capacity plant produces 10 cubic meters of sludge per year). Effluent output ranges about 1.5 times the plant capacity (e.g., a 10 cubic meter plant produces 14 cubic meters of effluent/year) (Sood, 1980). Chinese research has attained the production of 20,000 kg manure/year from a 7 m^3 plant (FAO, 1978). Sludge is often used directly on the fields for fertilizer; it is also used in composting in "slurry pits", which are usually filled with othe agricultural wastes such as grass, straw and bagasse. In China, when not required directly, it is mounded and plastered until needed. Most sludge is carted or hauled to the fields. In some cases slurry is channeled directly to the fields or used in irrigation systems. Few biogas plants have aquaculture ponds integrated into the materials flow system; however, Subramanian (1978) advocates this practice owing to the high yields and short life-cycle of biomass in water. Values for the chemical composition of digested effluent, slurry or sludge vary depending on the input materials, for instance, leguminous leaves increases the available nitrogen supply by more than twice as much as bagasse. One example of composition from Chinese experience is given in Table 30. Nutrient increases between input and effluent were approximately 14% for nitrogen and 19.3% for phosphorus (FAO, 1978). Subramanian evaluates the relative composition of digester end-products on the basis of the assimilable organic form to the ammonia form. Increases range from 10% to 24% (variability depending on input).

Table 30. Composition of Biogas Sludge and Effluent

	Input-Sludge	Output-Effluent
*N	650.0 ppm	500.0 ppm
*P	40.0 ppm	15.0 ppm
K	9,400.0 ppm	2,000.0 ppm
Organic matter %	35.0	

*available.

Source: FAO Soils Bulletin 40 (1978).

Digester sludge is dried when sludge is used for composting large volumes to be transported or when the sludge will not be used immediately. This practice volatilizes over 97 percent of the ammonia nitrogen (Subramanian, 1978). The ammonia nitrogen can be maintained by wet application and ploughing under of slurry. Most studies substantiate this, although one study of ICAR in India concludes that sun-dried slurry makes better fertilizer. Additional advantages over composting include decrease of weed seeds, plant pests and white ants. In chemical fertilizers, ammonium sulfate is usually four times as effective and available as compared to digested slurry or compost. The disadvantages of commercial fertilizers include high cost, well-known soil damage which occurs after repeated use, and no year-to-year carry-over. Both slurry and compost supply a more continuous source of nutrients, e.g., about one-third of the nitrogen becomes available each year during the three-year period (Subramanian, 1978). Mixing digested slurry with compost has been found to significantly increase the rate of composting, reducing the time required by as much as 75% (Sood, 1980). Increases in quality and

productivity of crops fertilized with digester as compared with commercially fertilized crops have been well documented. China production brigades reported increased tillering rates and number of spikelets observed in wheat crops (FAO, 1978). Experiments at Lalit Garden near Calcutta, West Bengal, indicate that the size and taste of crops was better with slurry, reported increases of the weight of root vegetables was 300% with night soil slurry irrigation, instead of normal irrigation. Other studies from India indicate that slurry has beneficial effects on grasses, sugarcane, rice fields and nurseries (Subramanian, 1978).

4. Aquaculture

Introduction. Aquaculture lagoons for sewage treatment, fish production, and irrigation have been used in numerous areas, in Asia, Africa, Europe and the Americas. In some areas, such as China, Sicily and India, this practice has been conducted for centuries (Reid and Coffey, 1978). There is ample evidence that aquaculture ponds give water quality results comparable to those obtained using conventional stabilization ponds (Stowell et al., 1979).

The relative importance of physical/chemical factors and various aquatic organisms (which compose the biological food chain) to water purification is controversial; however, most research indicates that each component has a significant role. Aerobic, facultative, and anaerobic bacteria function to degrade organic matter. Green algae, diatoms and blue-green algae are the primary oxygen producers. Protozoa, rotifers, fungi and crustaceans are important in minimizing turbidity and assimilating bacteria and algae (Reid and Coffey, 1978). Fish are the major consumers of the above types of organisms. Some species specialize in phytoplankton grazing, others on zooplankton (protozoa, rotifers, crustaceans, etc.). Careful selection of fish species can result in algal and insect control, and production of high quality protein. Sewage treatment can be effectively achieved with shorter retention times than that required for maximum fish productivity; management strategies to maximize both end products unfortunately are not the same. (Canter and Malina, 1978).

Physical and chemical factors which influence water purification include: absorption and sedimentation at the water-sediment interface; temperature, which affects the rate of organic degradation, biochemical reactions and oxygen production; solar and ultra-violet radiation which provide energy for photosynthetic oxygen production and breakdown reactions; wind which aerates and mixes the water column; evaporation and rainfall which alter the water levels in the ponds; and heavy rainfall which can cause increased mixing, break down of stratification and increased dissolved oxygen concentration.

Four basic types of aquaculture are practiced (Kalbermatten, 1980):

- freshwater fish culture
- mariculture (marine fish, shellfish and shrimp)
- algal production
- aquatic plant (macrophyte) production

Mariculture will not be considered in detail as it is not applicable to this project. Despite recent research efforts in aquatic plant and algal production, current data is limited, making technical and economic assessment difficult.

The major drawback of both these methods of aquaculture is the expense and complexity of harvesting and processing plants (very high water content) to achieve cost efficient, marketable products. More work has been conducted on fresh water fish culture than any of the above methods; Kalbermatten (1980) feels this is the only option available at this time for widespread implementation.

Fish Aquaculture. Cultured fish are a major source of protein for many low-income communities in the Far Eastern countries where the most common method of fish pond fertilization is use of human and animal

excreta (Kalbermatten, 1980). As the need for more efficient protein sources grows with expanding populations, fish aquaculture represents a vital protein resource that should be exploited. It is essential that planning and design of aquaculture systems are conducted in consultation with local fish farmers and other specialists. Aquaculture management training for local personnel is also important.

Many fish species have been cultured in sewage fed ponds (e.g., goldfish, fathead minnow, golden shiner, black bullhead, channel catfish, mosquito fish, bluegull, green sunfish, largemouth bass), however, the most successful species belong to two groups: carp and Tilapia. According to Kalbermatten (1980), the most useful aquaculture species are microalgae feeders including silver carp (Mypophthalamichtys molitrix), bigear (Aristichthys novilis), and two Tilapia (Sar otheroden mossambicus and S. niloticus).

The People's Republic of China is the world leader in freshwater fish culture; they typically culture several species of Chinese carp together (polyculture) (Ling, 1977). Fish production in a typical 1 ha. pond averages 3000 kg/ha annually (Bardach et al., 1972). In India, the most important polyculture carp systems include Catla Catla, Cirrhinus mrigala, Labco rohita and L. calbasu (Kalbermatten, 1980).

Alsten (1980) reported on recent research in the U.S. which indicates that among filter feeding fish, Silver and Bighead Carp are particularly efficient because each species has specially adapted gillrakers which allow much finer filtering capacity (to particles as small as 4 microns). In addition, both species are tolerant of low dissolved oxygen levels and grow rapidly (production averaged 4500 lbs/acre/year). In this study,

96 percent reductions in BOD and suspended solids in the six pond system resulted in a significantly improved effluent. The carp were rendered into fish meal which was assesed at a crude protein content of 55-57 percent.

According to a NAS report (1976), Tilapia spp. are hardy, prolific, fast growing, commercially valuable species able to endure stagnant "ditch" type conditions. Relative to other cultured fish species, Tilapia spp. are noted for their tolerance to brackish waters and have fewer assocated diseases and parasites (Bardach et al., 1972). Many of the Tilapia spp. (e.g., T. mossambicus), are filamentous algae and phytoplankton feeders, an important consideration in mosquito control. Filamentous algae protects mosquito larvae from predation and thereby provides an excellent breeding habitat for them. Thus, an integrated algae-mosquito control program can be provided by stocking aquaculture ponds with Tilapia filamentous algae feeders and the mosquito fish, Gambusia affinis.

Additional research on Tilapia and other fish in the Quasil Creek Sewage Treatment Plant, Oklahoma, USA (Canter and Malina, 1978) resulted in mean weekly BOD removals of 95 percent, suspended solids removal of 94 percent, significant reductions in nitrogen to phosphorus ratio, and fecal coliform bacteria. In this system, where the primary objective was waste disposal, representative production rates for Tilapia were increases of 1,500 to 4,300 lbs/acre in 191 days (catfish: 600 to 4,400 lbs/acre/ 120 days and shiners: 85-536/lbs/acre/120 days). This research empha- sized that when fish production is the primary goal, weight increases will be four to five times as much in the same time period, depending on the combination of species. South American Cichladae have received little

attention by aquaculturists because they are very prolific and tend to overpopulate their habitat, causing stunted growth (Lin, 1963). However it has been suggested that members of the large and diverse South American family, Characidae, could rival the yield from Chinese carp culture (de Menezes, 1966). Also, a freshwater fish in the Amazon basin, the Pacu, who gulps air in periods of low oxygen and grows rapidly on a herbivorous/filter feeder diet, is showing promise in experimental aquaculture research systems. (Kalbermatten, 1980).

Selection of non-native species to be used in aquaculture should involve careful screening under controlled conditions to avoid the potential hazard of competition with and elimination of native species. (NAS, 1976; Odum, 1959).

Various pond types have been used for fish aquaculture. Construction and maintenance of fish ponds is essentially the same as that required for waste stabilization ponds. Depths between one and two meters are recommended; greater depths are disadvantageous because the bottom layers become anaerobic and shallower lagoons become ideal for aquatic macrophytes (Kalbermatten, 1980). In Central Europe, where ponds of 1 to 2.5 feet depth have a loading rate of 800-1,000 people/surface acre of pond, dilutions of 2-5 volumes of clean water are used. Furthermore, ducks are used to keep aquatic weed growth controlled. Production levels are 400-500 lbs. fish/acre/year and 200-250 lbs. duck/acre/year. Yields from carp and Tilapia grown in maturation ponds range 200-100 kg/ha./year depending on management techniques. In general, facultative ponds are not used because the concentration of oxygen falls too low for fish survival, particularly on windless nights. In India and southeast Asia, several nutritionally

valuable species of catfish and snakeheads (air breathing fish) have been grown successfully in facultative ponds (Kalbermatten, 1980).

Fish production in aquaculture is highly dependent on species selected, volume and application of wastewater nutrients applied, stocking density and frequency of harvesting. Aquaculture in sewage supplied fish ponds has consistently resulted in up to a 70 percent increase in fish production despite 40 percent reduction in supplemental feed. (Allen and Hepher, 1976).

The salient findings from data on fish cultured in water supplemented with wastewater nutrients are given in Table 31. The range of productivity for fish reared in monoculture ponds is 500 to 3,977 kg/ha./year. The comparable range for polyculture ponds is 900 to 10,000 kg/ha./year.

More recently, Kalbermatten (1980) has figures for carp yields ranging from 200 to 1,000 kg/ha/year depending on whether they were produced in fertilized rural subsistence ponds or carefully managed commercial ponds. Tilapia yields in the latter ponds were estimated at 2,000-3,000 kg/ha./year and polyculture yields of up to 5,000 to 7,000 kg/ha./year are reported with supplementary feeding from sources such as grass, other vegetation, rice bran, groundnut cake etc. Other methods for increasing fish yield which Kalbermatten specifies include: addition of ducks to the system since their feces provide additional nutrients for algae, this practice increases fish yield 50 to 100 percent and the duckmeat provides a significant increase in overall protein production; use of polyculture systems which essentially allow a broader diversity of available pond

TABLE 31. REPRESENTATIVE YIELDS FOR CULTURED WARM WATER SPECIES OF FRESHWATER FISH IN WASTEWATER SUPPLEMENTED PONDS

	Number of Reports	$\bar{X}$ Yield kg/ha/ year	Range kg/ha/ year	Countries	Source
I. Monocultures					
• Cyprinus carpio Common Carp	3	1250	500-2000	W. Germany Poland Yugoslavia	Bardach, 1972
• Cyprinus carpio	1	7700	--	Madras, Inida	Muthuswamy, 1974
• Ictalurus nebulosus Brown Bullhead	1	2024	2024	USA	Bardach, 1972
• Carp spp.	1	1317.7	--	Kielce, Poland	Wolny, 1966
• Ictalurus punctatus Channel Catfish	7	2419	1527-3977	USA	Bardach, 1972
II. Polycultures					
• Tilapia nilotica					
Heterotis niloticus	1	--	900-3225	Cameroon, Africa	Bardach, 1972
• Tilapia spp.					
Hemichromis fasciatus	1	--	3000-10,000	Togo, Africa	Bardach, 1972
• Tilapia spp.					
Haplochromis mellandi	1	--	1000-1500	Zambia, Africa	Bardach, 1972

continued on the following page

Table 31. Representative Yields for Cultured Warm Water Species of Freshwater Fish in Wastewater Supplemented Ponds (cont.)

	Number of Reports	$\bar{X}$ Yield kg/ha/ year	Range kg/ha/ year	Countries	Source
II. Polycultures (cont.)					
. *Tilapia* spp.					
Cyprinus carpio Common carp	1	2500	--	Israel	Bardach, 1972
. *Tilapia mossambica*	1	1.6 tons/Ha	--	Hong Kong	Chan, 1976
Clarias fucus Catfish *Ctenopharyn godon idella* Grass carp *Aristichthys nobilis* Bighead Carp *Hypophtholmichthys molitris* Silver carp *Cyprinus carpio* Common carp					
. Rohu Calta Mrigal Silver Carp	1	7676 kg/ha/ 7 mos		West Bengal, India	Ghosh, 1974
. Various species ducks also used as a source of fertilization	1	1120 kg/ha/year	--	Northern Rhodesia (Zambia)	Mortimer, 1963

resources to be efficiently utilized; decrease prolific breeding which produces high density conditions particularly in the case of Tilapia where ponds should be stocked with fish of only a single sex (easily achieved through hybridization of male S. mossambicus with female S. niloticus, producing only male fish).

Empirical determination of the correct rate of supply of nutrients is important as findings are few and inconsistent. Kalbermatten states that generally 1 to 5 days retention time will neither waste nor provide insufficient nutrients for optimum fish yields. The mean doubling time of the algal species is an important factor which must be considered in determining retention time.

Three potential health problems are associated with fish farming in excreta - or sewage-fertilized ponds (Kalbermatten, 1980):

- the passive transference of excreted pathogens by the fish, which became contaminated in the polluted water;
- the transmission of certain helminths whose life cycles include fish as an intermediate host; and
- the transmission of other helminths with life cycles involving other pond fauna, such as the snail hosts of schistosomes.

The first problem, which may occur throughout the world, is related to pathogens which are passively carried in the intestines and body surface of the fishes. Since thorough cooking will destroy all excreted pathogens, the risk of infection exists only for people who prepare, handle or eat the fish raw (Kalbermatten, 1980). The helminth transmission is generally restricted to areas of the world where they are endemic and certain eating habits (such as eating raw fish) are found. The worms, which are parasitic to man have an intermediate fish host, and are

associated with excreta-fertilized fish ponds, are Clonorchis sinensis (Oriental liver fluke), Opistorchis viverrini and O. felineus. Fish must be thoroughly cooked to kill encysted larvae and preservation or pickling techniques are ineffective. With pretreatment, presettled or night soil which has been stored a few days prior to pond enrichment, eggs will have been eliminated through sedimentation or killed in storage (Kalbermatten, 1980). Salmonella, polioviruses, coksackie viruses, Shigella, cholera vibrios and enteric pathogenic viral hepatitis have all been implicated in fish and shellfish (Canter and Malina, 1978). Kalbermattern (1980) states that the following control strategies will eliminate (or reduce to acceptable levels) the health hazards associated with aquaculture utilizing human wastes:

- enrich ponds only with settled sewage or stored night soil or sludge;
- allow fish to reside in depuration ponds with clean water, several weeks prior to harvesting;
- clear vegetation from banks to discourage snails;
- promote good hygiene in all stages of fish handling and processing
- discourage consumption of undercooked fish.

Fish products which are used for producing animal or other fish meal is a further alternative which decreases the possibility of pathogen transmittance. The incorporation of these practices into fish aquaculture systems will permit the production of valuable pathogen-free protein at low costs.

Algal Production

This section briefly discusses the development of High-Rate Algal Pond Systems, the nutrient value of the harvestable algae and recent algal feeding experi- ments.

As Shelef et al. (1980) mention in their paper, the High-Rate Algal Pond (HRAP) system for the treatment of organic wastes and the production of algae for animal feed, originally conceived by Oswald and his group at the University of California, (Oswald, 1963, 1969; Gotaas and Oswald, 1954, 1958; Shelef, Oswald and Golueke, 1969) was further developed in Thailand by McGarry using night-soil (McGarry and Tongkasame, 1971), in Woods Hole, Mass. by Goldham and Ryther (1975, 1976) using wastewater-enriched seawater; in Israel using municipal wastewater (Shelef et al., 1973, 1976, 1978a, 1978b, 1978c); in Austrialia (Todd, 1976); in India (Venkataraman, 1979) and again in California (Benemann et al., 1977a, 1977b, 1980).

Agricultural wastes, particularly animal wastes, can also be treated by algal systems resulting in considerable biomass yields to be harvested as a source of animal proteins. Algae growth on piggery wastes was reported by DePauw et al. (1976, 1980) and on various animal wastes by Lincoln et al. (1977, 1980), on cattle dung in India by Seshadri (1979), and on digested and undigested cow manure by Shelef (1979).

Numerous studies in Israel and elsewhere (Mokady et al., 1980; Yanni et al., 1980; Lipstein and Hurwitz, 1980; and Sandbank and Hepher, 1980)

showed that high rate pond harvested biomass can safely substitute conventional proteinaceous animal feed ingredients such as soymeal and fishmeal in feeding of poultry and fish. The value of such substitution feed is between U.S. $200 and U.S. $300 per ton. Adding the value of the recovered biomass to the cost of producing a high quality effluent (Table 32) (including nutrients removal) by any available wastewater treatment technique renders the two-stage high rate pond system to be economically attractive under conditions of favorable climate and land availability.

More recently, Shelef (1981) has studied the use of biomass from HRAP as animal feed. HRAP biomass following harvesting by alum flocculation, flotation and drum-drying served for extensive large scale animal feeding experiments and nutritional and toxicological studies. The biomass contained approximately 55 percent algae and the rest was mainly bacterial biomass and inanimate material. The total protein content was between 42 and 52 percent.

HRAP biomass was used for extensive feeding experiments of the commercially grown fishes Cipprinus carpio and Tilapia galilea grown in various sizes of aquaria and ponds, including commercial full-scale ponds (Hepher et al., 1978; Sandbank and Hepher, 1978, 1980). The algae was pelletized with other ingredients composing commercial pelletized fish ration while replacing all of the fishmeal portion. Approximately 22 percent of dry algal biomass replaced the commonly used 15 percent fishmeal in the pellets (based on equo-protein level). Although the aluminum content of the dry algae amounted to between 3 and 6.5 percent, fish growth rate, weight gain and general health were equal or in most cases superior to the fish fed with commercial food containing fishmeal. No differences were found

Table 32. Effluent Quality Expected in a Two-Stage High Rate Algal Pond System under Favorable Operational Conditions

	Raw Sewage mg/l	First Stage Pond Effluent mg/l	"Course" Flotation Effluent mg/l	Second Stage Pond Effluent mg/l	"Refined" Flotation Effluent mg/l	Final Effluent (Filtered and chlor.) mg/l
Total susp. solids	528	366	80	268	20	5
Algal susp. solids	-	208	65	215	-	-
Bacterial susp. solids	-	146	15	42	-	-
BOD_5, total	412	140	30	70	10	4
BOD_5, dissolved	-	23	20	5	4	3
COD, total	978	816	160	548	55	25
COD, dissolved	-	80	75	30	25	20
Nitrogen, total	93	68	38	24	3	2
Nitrogen, dissolved	-	33	32	3	2	2
Phosphorus, total	18	16	3.5	3	0.2	0.1
Phosphorus, dissolved	-	9	2	0.2	0.1	0.05

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Source: Shelef

when the predominant genus had been changed according to the season and pond location and Englena, Micractinium, Scenedesmus, Chlorella and Oocystic (all chlorophytes) showed virtually the same nutritional value. The addition of phosphate additive to the pellets further increased the rate of weight gain of the fish significantly over fishmeal-based commercial diet.

Extensive nutritional experiments with broiler chicks (Mokady et al., 1978, 1980), and with laying hens (Hurwitz and Lipstein, 1978, 1980) showed that when HRAP alum flocculated drum-dried algae substituted 25 percent of soybean meal in the diet of poultry, the rate of weight gain and general health of the birds were equal to those attained with commercial feed. Soybean meal could be substituted up to a level of 50 percent (except for chicks of up to 4 weeks of age) but intensive yellow coloration of the skin and yolk occurs. This coloration, which is caused by the high concentration of xanthophyll, can become disadvantageous in certain markets or advantageous in others. Intensive toxicological studies were carried out on the algal biomass feed, using test animals for both the biomass itself and the flesh of the animals fed on the algal biomass (Yannai et al., 1978, 1980). No maleffects were observed nor any abnormal accumulation of heavy metals in the edible organs of the marketable animals. A recent work published by Yannai and Mokady (1980) showed distinctly that HRAP biomass can substitute a third of the soymeal in poultry rations and that no significant absorption of heavy metals by the animals was observed even when the heavy metals content of the algae was higher than the control rations.

The growing industry of aquaculture and mariculture opens a new use of HRAP biomass utilization for feeding of shrimp and prawn larvae which are

obligatory algae feeders as well as for feeding bivalves (De Pauw et al., 1980; Horstmann, 1980). HRAP biomass has been used successfully for feeding of the giant prawns Macrobrachium rosenbergii in aquaria and ponds (Finkel et al., 1979 and Phillips et al., 1981) at the Technion, Israel.

Economic Considerations

The recent experience with large scale outdoor algae ponds (Table 33) lead to reduction in the cost of algae production even when grown for human consumption on inorganic media. The cost of production of dry Spirulina by Sosa Texcoco in Mexico has been reduced to between U.S. $1 and $2 per kg (Santillàn, 1980) and Heussler et al. (1980), estimated the cost of production of drum-dried Scenedesmus for human consumption in large scale ponds at about U.S. $1.75 per kg. The economics of HRAP system are considerably more attractive since there is no cost involved in fertilizers and carbon source, no need for expensive pond lining and there is no need to maintain an axenic culture. In addition, the cost of the HRAP system is shared by the benefit of wastewater treatment and production of high quality effluent. Deducting the cost of secondary wastewater treatment, which is required to produce effluent of similar quality as that attained by HRAP, yields a production cost of about U.S. $120 per metric ton of drum-dried algal biomass and of less than U.S. $80 per ton of sun-dried algae. This should be compared with the current cost of soymeal which ranged between $180 to $230 per ton or (on equo-protein basis) with the cost of fishmeal which ranges between $280 to $400 per equivalent ton. Using the HRAP biomass in a heat-treated semi-wet form (approximately 25 percent solids) will further decrease its cost.

TABLE 33: Algal Production Facilities with Pond Area of Over 1000 m^2

Place	Total Size Hectares	Media	Type of Algae	Harvesting	Use	Ref.
Saosal, Peru	0.25	INOR + CO_2	Scenedesmus	Yes (C,DD)	Human Proteins	6
Richmond, Calif.	0.20	MWW	¢	Yes (C,DD)	WWT, AF	7
Yagur, Israel	0.2	MWW	¢	Yes (Floc.,F,DD)	AF	8
Singapore	0.25	AW	¢	Yes (Floc.,F,DD)	AF	9
Eilat, Israel	2.0	MWW	¢	No	-	8
Eilat, Israel	3.0	Saline+$NaHCO_3$	Dunaliella	Yes (C,Ex)	Glycerol & Carotene	10
Gainsville, Florida	0.4	AW	¢	Yes (Floc.,SD)	AF	11
Taiwan & Okinawa, Japan	25.0	INOR + CO_2 or mixotrophic	Chlorella, (Spirulina)	Yes (C,FD or SD)	HHF (Animal Feed Pigments	12
Sasa Texcoco, Mexico	30.0	Soda brine	Spirulina	Yes (Fil., DD)	Fish Culture, Pigments, HHF	13
St. Helena, Calif.	6.0	MWW	¢	No	WWT	14
Hollister, Calif.	15.0	MWW + IW	¢	No	WWT	14
Modesto, Calif.	15.0	MWW + IW	¢	No	WWT	14
Tel Aviv, Israel	120.0	MWW	¢	Yes (Floc. DD)	WWT, GWR, AF	8
Rupité, Bulgaria	0.3	INOR, AW	Scenedesmus Chlorella	Yes	HHF, AF, Cosmetics	42

AF - animal feed; AW - agricultural wastes; C - centrifugation; DD - drum drying; Ex - extraction; F - flotation; FD - freeze-drying; Fil. - filtration; Floc. - flocculation; GWR - groundwater recharge; HHF - human health food; INOR - inorganic media; IW - industrial wastes; MWW - municipal wastewater; SD - spray drying; WWT - wastewater treatment

Source: Shelef, 1981.

Aquatic Plant Production.

In aquaculture lagoon systems, aquatic plants function as water treatment processes by: producing free oxygen through photosynthesis; shading and cooling sediments of the littoral zone; slowing water movement to aid in nutrient absorption; helping to convert inorganic materials to organic matter; anchoring the soil in place by means of their attenuated root system; attenuating sunlight which prevents excessive algal growth. In addition, aquaculture lagoons can be made commercially useful.

The efficiency of a marsh or lagoon system is based on the following factors:

1. Species and density of plant population
2. Design (shape, size, and substrate type) of the system
3. Type of substrate
4. Retention time of wastewater in the system
5. Growth cycle and growth type (emergency, submergent, floating) of plant
6. Toxic materials in the wastewater (certain toxic materials may become phytotoxic to the plant species as they accumulate)
7. Environmental factors such as photoperiod, temperature, pH, and water depth
8. Nutrient uptake rates of species in the system
9. Frequency and maintenance of plant harvesting

An overview of lagoon or retention pond systems indicates that many marsh and aquatic species have been successfully used. Some of these are shown in Table 34. Work has been conducted recently on the potential of integrated (several species) plant aquaculture systems (Blackburn, unpublished reports).

Table 34. Aquatic Vegetation Species Used Successfully In Lagoon or Retention Pond Systems*

Water hyacinth	*Eichhornia crassipes*
Water lettuce	*Pisria stratiotes* L.
Alligatorweed	*Alternanthera philoxeroides*
Duckweed	*Lemnaceae*
Cattail	*Typha* spp.
Bulrush	*Scirpus* spp.
Sedge	*Cyperus* spp.
Rush	*Juncus* spp.
Aquatic grass	*Gramineae*
Algae	*Chara* spp. *Pithopora* spp.
Submerged aquatics	various genera

*Compiled by: Robert D. Blackburn, Joyce Environmental Consultants, Flordia.

Productivity. Productivity values in these systems vary depending on the species used and the harvesting schedule. Scarsbrook and Davis (1979) conducted a growth study on five vascular aquatic plants using sewage effluent. Of the five plants (water hyacinth, alligatorwood, curly pondweed, *Egeria*, and slender naiad), water hyacinth had the highest growth response to the extra fertility. Water hyacinth was found to increase from an average initial weight of 2.0 grams to a harvested weight of 736.6 grams after a 23 week period. Alligatorweed and curly pondweed increased from 0.6 grams to 20.4 grams and 0.5 grams to 4.7 grams, respectively. Therefore, water hyacinth had the greatest productivity because of both the extreme increase in its growth and the high concentrations of N, P, and K in the plant tissue.

Nutrient Uptake of Aquatic Vegetation. Nitrogen and phosphorus occur in plant tissues at an average ratio of 10:1. This is the ratio at which these elements often are present in natural waters and is suggested as a guideline for indicating water quality conditions (EPA, 1978).

Nutrient removal capacity of aquatic plants (i.e., uptake rate, nutrient source and nutrient distribution within the plant) is currently a topic of active research and controversy. Published results indicate significant variability (Valiela and Teal, 1978; Boyd, 1970). Boyd states, "No average chemical composition for an individual species or ecological group based on data in the literature would be reliable." Nutrient sources of aquatic macrophytes are disputed (Good et al., 1978). In general, submergent and floating plant species obtain a greater percentage of nutrients directly from the water than do emergent species which use sediments as an additional nutrient source (Lindsley et al., 1976; Mason and Bryant, 1975). The distribution of nutrients within a plant varies with species, environmental conditions and growth phase. Despite the need for further research, luxury consumption (i.e., active uptake of nutrients against a concentration gradient, beyond the plant's physiological requirements) has been repeatedly established (Gerloff and Krombholz, 1966). Sediel (1976), reports that the number of macrophyte species known to have a positive effect on contaminated water exceeds 200,000. Moreover, the importance of aquatic vegetation in functioning as a nutrient sink, wastewater purifier and sediment trap is well documented by numerous field studies (Stowell et al., Sloey et al., 1978; IEP, 1979).

The quantities of nutrients that are potentially removable by various aquatic plants can be calculated from yield and mineral composition data. For example, a plant type which produces two tons of dry matter per acre per year and contains two percent by weight of potassium can remove up to 80 pounds of potassium per acre. Using this type of calculation, one can use the information reported in the literature to obtain the maximum annual uptake of several species. The questions 1) what levels of

nutrient removal may we expect from four selected aquatic plant types and 2) do some types perform better than others, are answered in Table 4-3. Comparison of the species in this table, which have been studied more extensively than most aquatic plants, indicates considerable differences. Water hyacinth has the highest mean annual removal rate for both nitrogen and phosphorous. Typha spp., Lemna spp. and Hydrilla verticillata have increasingly lower removal rates. Research on nutrient uptake by cattails, alligatorweed, bulrush, sedge, rush and scirpus is sparse. Because water hyacinth has become a major problem in US waterways, research has been concentrated on this plant. Water hyacinth has a tremendous potential for removing nutrients fron enriched waters because it has a high capacity of "luxury" consumption. The amount of nutrient removal is related to the growth rate of the plant.

Wahlquist (1972) conducted a study in confined 0.04 ha. earthen ponds showing the effect of fertilization on growth of water hyacinty. Inorganic fertilizer was applied at rates of 23.4 kg NH_4NO_3 and 16.6 kg P_2O_5 per ha. Ponds receiving no fertilization produced a standing crop (wet weight) of 174.5 metric tons/ha. while ponds receving P_2O_5 produced 550.4 metric tons/ha. Ponds receiving both P_2O_5 and NH_4NO_3 produced a standing crop of 590.9 metric tons/ha. Analysis of data showed a significant difference between ponds receiving P_2O_5 and those receiving none. Since the water was not analyzed for nitrogen and phosphorous, no comparison of uptake can be made.

Van Vuren (1948) stated that water hyacinths are especially suited for the removal of nutrients from effluent lakes. He found that one area of hyacinths, grown under ideal climatic conditions, could remove 3,075 lbs.

of nitrogen per year. Sheffield (1967), using water hyacinth as a biological means to remove nutrients from sewage plant efflutent, found that with proper climatic conditions and harvesting, one hectare of water hyacinth could remove, 2,744 kilograms of nitrogen per year. Further, the study showed that treated effluent (90 percent treatment), when placed in retention ponds containing water hyacinth, had a 99 percent removal of nitrates, ammonia, and phosphate.

A review of the existing knowledge on the use of aquatic plants for water purificiation indicates water hyacinth is the most efficient species, especially in subtropical and tropical regions.

Harvesting. Harvesting aquatic vegetation in aquaculture lagoons requires nonconventional methods. Recent innovations in aquatic harvesting technology have made this process relatively economical. A wide variety of harvesters have been developed for different depths, substrate types and aquatic species. Processing and utilization of harvested plant materials has received much attention recently (Smith, 1980; Livermore and Koegel, 1979). Some of the current uses of aquatic plant products include: agricultural mulch, livestock feed supplements, paper production and as mentioned previously, biogas production (Pirie, 1970, Bagnall and Hentges, 1979).

Land Application of Waste Waters and Aquaculture Pond Effluents

Extensive review of the literature indicated that most of the work to date has focused on the direct application of raw or treated sewage to agricultural lands. Those studies which described integrated systems gave little quantitative results regarding land application of aquaculture pond

effluents. As a result of this focus, the literature presents two goals, water treatement or maximum crop production, which are often not integrated or studied simultaneously. Ideally, an integrated sytem should achieve both final effluent treatment and increased crop production owing to the high fertilizer value of the applied waters; while most research emphasizes the use of conventionally treated secondary effluents, a few studies do indicate the benefits of utilizing effluents previously lagooned (sometimes for aquaculture purposes) and/or digested. Fedotor (1972) reports higher yields from effluents derived from a series of settling ponds. Wastewaters not receiving this treatment clogged the soil. Smith (1971) emphasizes the necessity of lagooning digested sludge prior to land application in order to reduce the nitrogen content. His findings indicate that excess applications of digested sludge result in accumulations of nitrate in the soils and potential ground water contamination. Another investigator, Marsh (1975), recommends pretreatment of municipal sewage in a simplified manner prior to using the nutrient-laden waste- waters as a beneficial resource for selected agricultural crops.

Several factors contribute to the final treatment of wastewaters used in land application systems, these occur primarily in the soil-vegetation complex. Land application systems using one of the three methods of spray irrigation, rapid infiltration and overland flow have achieved higher levels of water treatment at lower costs than conventional advanced wastewater treatment systems repeatedly used in the developed countries.

Vegetation cover in land application sites seems to enhance the capacity of the soil to accept and renovate waste (Loehr et al., 1979). The mechanisms by which crops contribute to renewal of wastewater include:

(1) erosion control; (2) increase and maintenance of infiltration; and (3) transpiration which accelerates drying of the soils and absorption of nutrients. In addition, plants provide economic benefits in the form of harvestable crops. Nitrogen and phosphorous generally occur in a ratio of 10:1. Nutrient removal by crops varies with the species, length of growing season and nutrient loading (EPA, 1976); however, nutrient removal efficiency decreases as the loading rate increases (Lance, 1972). Overman (1972) reports that high phosphorous fixation capacities of the soils allow for the removal of most of the phosphorous. This characteristic applies to many soil types which have been used at land application sites. Accurate estimations of nutrient removal rate of various crops consider the amount of tissued removed, the efficiency of the particular crop and the variation of nutrient concentrations in different plant parts.

Agricultural crops typically utilized in wastewater application systems can be divided into three categories based on their nutrient removal rates. The large range of removal rates accounts for species variation in each group; exceptions to this categorization do exist. Nitrogen removal for forage crops occurs at a rate of 170-670 kg/ha-year or more, field crops remove 80-170 kg/ha-year and forests remove 22-110 kg/ha-year (EPA, 1976). This relationship is indicated in Table 35. Corn and sugar cane have been used successfully in large-scale wastewater application systems, (Lau, 1974; Demirgian, 1975). Sugar cane is the vegetation cover used for a large tropical land application of sewage effluent project at Oahu, Hawaii. Muskegon County wastewater treatment program selected corn as the primary crop based on its compatability with both the goals of the system and the soil-water-weather conditions at the site (Demirgian, 1975).

Table 35. Reported Nutrient Removal by Forage Crops, Field Crops, and Forest Crops

	Nitrogen Uptake (KG/HA/YR)
FORAGE CROPS	
COASTAL BERMUDA GRASS	538-672
REED CANARY GRAA	253-402
FESCUE	308
ALFALFA*	174-246
SWEET CLOVER*	177
RED CLOVER*	86-141
LESPEDEZA HAY	146
FIELD CROPS	
CORN	174
SOYBEANS	105-127
IRISH POTATOES	121
COTTON	74-112
MILO MAZE	91
WHEAT	56-85
SWEET POTATOES	84
SUGAR BEETS	82
BARLEY	71
OATS	59
FOREST CROPS	
YOUNG DECIDUOUS (5 YRS)**	112
YOUNG EVERGREEN (5 YRS)**	67
DECIDUOUS (5 YRS)**	34-56
EVERGREEN (5 YRS)**	22-34

*Legumes remove substantial N from air, values for percentage removal from air versus soils is unspecified.

**Estimated

Adapted from: EPA, 1976.

Another crop type often used in land application systems is forage crops (including turf and sod grasses) for animal consumption. The utilization of treated effluent for irrigation of turf-grass is a common cultivation practice in many areas of the United States (Myers, 1978). When applied to turfgrass, the irrigation demand on the surface and groundwater supplies is considerably reduced. Apparently, the most efficient wastewater renovation systems are based primarily on forage crop production due to both their high level of environmental tolerance (to salinity and nitrates occuring in wastes) and their high capacity for nutrient uptake.

Controlled experiments on lands irrigated with potable water, wastewater and mixtures of the two resulted in the following conclusions: (SRH, 1974) productivity is primarily a function of the condition of the soil; several basic crop types grow better with wastewater irrigation; wastewater should not be applied to lands where drainage is deficient or fine-textured soils are present or the crops are not tolerant to saline water. However, these conclusions were derived from the application of wastewaters which had not been through an integrated system.

Much research on a wide range of application rates (4.5 to 45 tons manure/ha) has been conducted, but the results have limited use in predicting maximum loading rates at a particular site for optimum crop production and environmental quality (Smith, 1971). Kotia (1971) gives tables for specific applicatures in various soil types at different locations in the state of Gujarat, India. Furthermore, he discusses management problems occurring in Gujarat sewage farms. Lewis (1980) concludes that although land treatment of wastes has its adantages and

disadavantages, patterns of water use indicate that the need and demand for water will continue to rise in the future and that land application systems will help to meet this demand.

The advantages of land treatments include:

- It is a method of water treatment as well as method of resource recovery.
- The use of nitrogen, phosphorous and other elements for irrigation of crops can reduce the demands for artificial fertilizers and minimize the contribution of these nutrients to the eutrophication of streams and lakes.
- The reclaimed water, having undergone sufficient treatment for reuse, can economically supplement groundwater supplies.
- Land treated wastewaters are kept out of surface waters used for drinking purposes.
- In general, land application systems can be considerably less expensive, and more cost-effective than tertiary treatment facilities yielding water of similar quality.
- Land application can be operated with a minimum of environmental and health hazards.

The disadvantages of land treatment include:

- operational problems due to cold weather
- problems related to the requirement and availability of land
- a large dependence on local conditions.

B. Survey of existing IRR Systems and Research

1. General Background

Table 36 shows the categories of processes or activities which can constitute an integrated resource recovery system. Selection of a particular train of processes depends, of course, on a tremendous number of environmental, economic and social considerations, but before any IRRS can be considered, the wastestream(s) in question must meet the following conditions:

1. It contains a relatively high concentration of biogradeable organic matter.
2. It contains an appreciable concentration of nitrogen, phosphorous and other macro and micro nutrients.
3. With the exception of the piped sewerage part (if applicable), the waste stream has a high solids content ranging from 1 to 35 percent.

These characteristics of the waste stream and the need for maximum resource recovery indicate that the integrated system should contain a combination of any of the following unit of processes: (a) anaerobic digestion (fermentation); (b) composting; (c) algal-bacterial process (either high-rate or slow rate).

The main beneficial recoverable resources can be: (a) biogas; (b) water for irrigation; (c) organic fertilizers; (d) animal proteins, and (e) fish and duck farming utilizing both the water, the nutrients and the proteins. Some of the most favorable combinations of the above processes and the results of their implementation are discussed next.

Table 36. Processes or Activities for Resource Recovery

Direct Recovery	Land application (including land disposal)
	Direct utilization (including energy)
Microbial or Enzymatic Biodegration	Anaerobic digestion
	ansilage
	composting
	fermentation and enzymatic hydrolysis
	lagoon/pond
	sewage treatment plant
Thermo/Chemical Transformation	Acid hydrolysis
	Incineration
	Pyrolysis
	Gasification/hydrogasification
Others	Mechanical material separation
	Distillation

2. General Review of Existing Biogas Plants and Integrated Resource Recovery Systems

Introduction

The principles underlying integrated resource recovery systems (IRRS) with multiple inputs and outputs have been used and investigated for many years in different areas of the world. Despite this fact, little systematic research has been published on IRRS even in recent years. Most of the existing work does not indicate in any comprehensive way the specific composition of the waste streams; the operational impacts that changes or fluctuations in residue composition have on the operation of the processes; the significance of the prevailing social environment with regard to the particular system configuration; the ease or difficulty of expanding the proposed or practiced system (for instance with respect to collection and transport); or what operational, institutional, social and economic bottlenecks exist for the particular system. In lieu of such deficits in the literature, this review will focus on the extent of research and development on IRRS and their components, particularly biogas plants.

Review of the literature revealed that the majority of IRRS are relatively small-scale (single family, institutional or several family size), or designed for large livestock operations. Few community-scale operations exist. In addition, most systems are in the early stages of implementation or are pilot plants in the investigative phase. The operating systems occur predominantly in India, China, Thailand, the Philippines, Israel, Korea, Taiwan and the United States. A high level of diversity

exists in IRRS components, design and operation; to a large extent, these factors are determined by local expertise, resources and environment. Both the components utilized in most IRRS and the general types of waste streams used and products recovered are similar from system to system. The basic design for IRRS includes the following components: collection method (generally not specified in detail), biogas digester, series of various types of ponds ending in aquaculture ponds, effluent which is recycled or used for irrigation and sludge which is used for agricultural fertilizer.

This section of the report will summarize existing IRRS and the extent of use of each basic component of IRRS as outlined above. The following section will examine the state-of-the-art of the components currently in use. A large portion of the information from specific countries was derived from Subramanian's (1978) thorough survey of the status of biogas systems in Asia.

India. The Indian Council on Agricultural Research (ICAR) has studied biogas systems since 1938. Significant use of small-scale plants began around 1951 with the adoption of a single unit gasholder digester from the Chinese. Khadi Village Industries Commission (KVIC) has developed a biogas design which is commonly used today. Single family size plants with a volume between 3 and 7 m^3, a 55 day retention time, unheated and unstirred are typical. To date, nearly 74,000 biogas plants have been built in India (Sood, 1980). Various institutes in India including the Gobar Gas Research Station, Indian Institute of Technology, India Institute of Science, National Environmental Engineering Institute and others, are actively conducting research on new biogas plant designs

with innovations such as heating, insulation, stirring mechanisms and various inputs. The majority of Indian plants (70 percent) were built during the 1975 to 1976 fuel and fertilizer crisis (Subramanian, 1978). Several institutes have larger plants, these include: Parasalethi College, Tenkasi-Tamil Nadu (17 and 28 m^3, providing by means of a boiler, steam for the cooking needs of 730 people); Tulsi-Shyam Temple - Gujarat (85 m^3, 300 cattle, for 7.5 KVA power, flour mill, water pump and small scale industrial power; the central jail - Nagpur, Maharashtra.

Semi-community plants include: one operated in 1969 and 1970 in Khiruda, Panchayat (several public toilets fed three digesters, 5.5, 14 and 25 m^3, which lit two city streets); VSF Cooperatives, KCP Sugar Factory, Vayura-Andhra Pradesh (35 m^3, 70 buffalo and sugar press mud, supplies gas to 14 families 3 hours daily); Mudhavaram Dairy - Madras (14 m^3, 7 houses (50 people), 9-11 hours gas daily); Kasturba Gram Krishi Kshetra, Indure (70 m^3, gas to 40 families, 14-24 hours daily). Community plants are planned and possibly operating by now at Digras-Maharashtra (20 animals, 10 community toilets, gas for 10 families); Karimnagar-Andhra Pradesh (128m^3m, 300 cattle, gas for 30 families and five 3.5 kw irrigation pumps); Fatehsingh-kar Purwa, Etwah-Uttar Pradesh (operating since early 1979, 35 m^3 and 45 m^3 plants, 127 cattle, gas for 27 families, cooking, lighting (street and home), water pumping, threshing, flour milling, chaffing), (Ghate, 1979; Bhatia and Niamir, 1979); a private plant in Valrod-Gujarat (85 m^3, 60 cattle, gas for 25 houses) (Cecelski et al., 1979). Despite substantial government subsidies, successfuly operation of community-scale biogas plants is limited to the last few years. Even with the community-scale biogas plants, method of collection is largely by individual (family or plant employee) transport. The

available literature does not specify percentage use of output effluent. Although aquaculture in stabilization ponds is a relatively common practice in India (see section on aquaculture), integration with biogas systems has not been reported. Effluent and sludge are used for agriculture (effluent is used directly for irrigation, sludge is either composted first or applied directly). There would be distinct advantages of increasing integration in the few community systems presently in operation.

Korea. The Office of Rural Development (OFD) has been instrumental in establishing 27,000 small-scale digesters since 1969. Large-scale heated digesters have been developed and one was operating in 1976 at the Livestock Experiment Station (Suweon, 155 m^3, 40 family, 170 cattle, mechanically mixed). Experiments with different digester designs, heated designs and the use of algal cultures to use up CO_2 in the gas are underway at the Institute of Agricultural Engineering and Utilization, College of Agriculture, Suweon. Cattle and pig excreta and night soil are the major inputs. The output gas is used primarily for cooking, a small percentage is used for home heating. In addition, the slurry is hand carried to the fields, mixed with compost and applied as a soil conditioner. The direct application of diluted slurry to the fields is practiced at the Livestock Experiment Station. Although psychological inhibitions against its use exist, a primary school runs a biogas plant on night soil; the army has expressed interest in this method of operation (Subramanian, 1978). The apparent level of integration is low; however, some aquaculture is practiced.

The Philippines. The National Institute of Science and Technology (NIST) has supported the construction of approximately 100 small scale units (5-10 pigs, gas for 5 people). The gas is used primarily for cooking, however, owing to the abundance of fuelwood, the major incentive for plant use is to enhance public health conditions and control pollution. Pig and some buffalo manure are the common sources of waste; night soil is used despite some psychological inhibitions (Subramanian, 1978). The resources of the Philippines include an abundance of agricultural waste relative to the quantity of animal wastes. As a result, the use of agricultural wastes is increasing and research on their potential uses expanding. The Philippines has two IRRS. At the University of the Philippines - Los Bunos, a small-scale integrated system operates from the wastes of 10 pigs to produce gas for the cooking needs of five people. The system has two digesters in series, the slurry proceeds from these to two settling tanks and is then channeled to an algal/fish pond where Chlorella and various fish are produced, the effluent is then used for irrigation of the rice fields. Windmill power is used both to stir the algal culture and to transfer liquids through consecutive stages of the system. The research at this system has focused on detailed process investigation (Eusebio and Rabino, 1978). For example, among the potential urban and rural waste inputs swine feces and urine are considered to be some of the highest energy sources, producing about 65 percent methane under mesophilic conditions and about 61 percent under thermophilic conditions. Different pH, temperature, loading and dilution rates, solar exposure, retention time and percent addition of fibrous crop residue are under investigation regarding their influence on gas generation and the resultant fertilizer value. A basic need is to determine in various

regions that combination of local organic wastes which provides the most efficient production of methane.

Maya Farms, another IRRS operating in the Philippines, is the largest Asian biogas establishment (Subramanian, 1978). 7,500 to 15,000 pigs provide 48 large batch digesters with 5 tons of dung every other day. Daily gas production of the whole farm is between 560 m^3 to 840 m^3 depending on the total number of animals. Table 37 indicates the uses of biogas at Maya Farms.

Table 37.
Uses of Biogas at Maya Farms

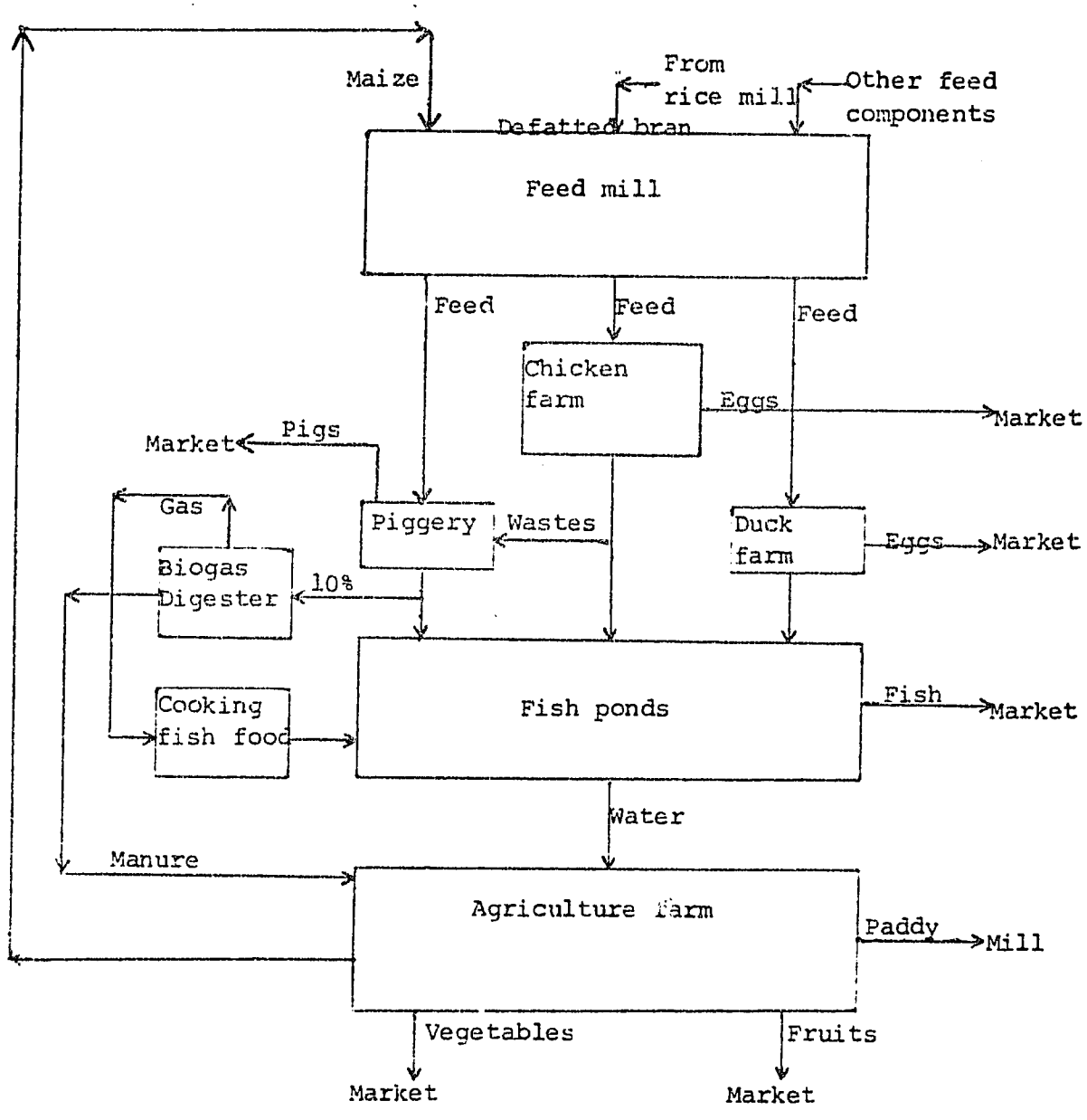
- Power two pumps handling 400 GPM for 12 hrs. each day.
- Power a 60 KVA generator which runs freezers 12 hrs. each day.
- Power a 12.5 KW generator which supplies electricity to the farmhouse, dormitories, pig pens, and the main roads of the compound.
- Cooking and water heating in the meat processing and canning plants as well as for heating water in the slaughter house.
- Brooding in farrowing pens.
- Dryer in rendering plant.
- Rice dryer.
- Lighting, cooking, water heating, refrigeration, and ironing.

Source: Subramanian, 1978.

After the sludge passes through a series of ponds where it is diluted, aerated and aged, it has a variety of uses including: agricultural fertilizer and nutritional supplement to hogfeed (high in nutrients, particularly vitamin B_{12}). The supernatent is treated by aeration in a series of waterfalls; it is also used in a combination of Chlorella algae and Tilapia fish production ponds (Diaz and Golueke, 1979).

Thailand. As early as 1965, a demonstration biogas plant was built by the Division of Agricultural Economics, Ministry of Agriculture. Development since then has lagged as a combined result of the abundance of fuels such as wood and charcoal and the shortage of livestock. Several private and government organizations are currently investigating various biogas systems, including those utilizing night soil. There are approximately 225 small-scale units (2.8 m^3, cattle and pig wastes, cooking gas for 5-7 people) in operation in Thailand. Kasetsart University built four family units for research and demonstration purposes (Subramanian, 1978). Digested sludge is not commonly used as fertilizer, most farmers prefer to use commercial fertilizers. A small-scale IRRS, the Farm Kirikan in the Pathumthani Province of Thailand, attempts to integrate the production of poultry, pig, fish, rice paddy, vegetables, and fruit by the utilization of residual waste streams as input to biogas digesters and fish ponds. Figure 8 shows the material flow through the Farm Kirikan system. The energy, feed and other byproducts generated are used as input to the overall farm production/consumption process (Enfo, 1979). Currently, this system is being studied by AID in order to optimize the material flows and processing.

Figure 8. Flow Diagram for Farm Kirikan



Source: Enfo No. 2 April 1979

The study of two systems for the treatment of urban night soil has been stimulated by Thailand's urgent urban sanitation problem. The results will be evaluated for potential improvements in the existing septic tank system in Bangkok (AIT, 1979). One study involves a septic tank with an anaerobic upflow filter to further treat the septic tank overflow. The second system is a vault or privy system from which night soil will be collected. Researchers are considering the feasibility of recycling the sludge to fish ponds stocked wtih Tilapia nilotica (herbivorous feeders on the phytoplankton grown from human waste). To reduce possible pathogen transmittance, waste fed fish will be used as feed for production of carnivorous catfish and shrimp which have a higher market value. Two alternatives will be used in the system for "pretreating" the night soil; one will be composting it with vegetable matter, the other will use it first in biogas plants, then in compost.

An Asian Institute of Technology research study is using a combination of high rate stabilization ponds and fish ponds to treat sewage and recover the nutrients (Enfo, 1978). Raw sewage enters an aerated stabilization pond (via an equalization tank). After detention it is pumped through a series of fish ponds. The large size Tilapia nilotica are marketed, while undersized fish are used as feed for catfish, shrimps and prawns. The algal-rich final effluent is used for agricultural crops. Once preliminary research is completed, a larger scale system is planned on which commercial viability evaluations will be used.

New Guinea. In Vanimo, Papua, construction of a hospital waste digester was recently reported (Frankel, 1977). Only human wastes from the hospital location were used in order to have a system straightforward

enough to function with as little attention to operation and maintenance as possible. As long as the lavatories are flushed, the system continues to function without major effort. If animal wastes were included in the operation, transportation, collection and input of wastes to the digester would be required every day, in addition to care and feeding of the animals. The wastes enter a modified (sealed) septic system, where methane is generated and collected. The effluent enters a second tank where digestion continues and particulate matter settles out. From there it flows into a shallow pond; here sunlight accelerates the process of oxidizing any remaining organic material and stimulates the growth of phtosynthesizing algae. This tank's effluent is ready for reuse. The water in the tank is odorless and bright green in color from the rich concentration of algae, which can be collected from the surface, dried and used as animal feed, or used directly as feed for fish (Tilapia), ducks, and freshwater prawns. The final effluent is channeled through irrigation pipes to fertilize gardens. The fluid is then used to irrigate and fertilize gardens. The system is operated entirely on human waste from the lavatories and system outputs include: gas for three cooking stoves and a gas light, 2,000 lbs fish/year, 200 table ducks/year and reportedly flourishing gardens. In this case, where there was a need to construct a waste disposal system the returns on a moderate capital investment were impressive (Frankel, 1977).

China. The Chinese have traditionally returned all urban wastes to the soil. Furthermore, the principles of IRRS have undergone much development and refinement through thousands of years of practice. The most important output of the IRRS for the Chinese is fertilizer and soil conditioner.

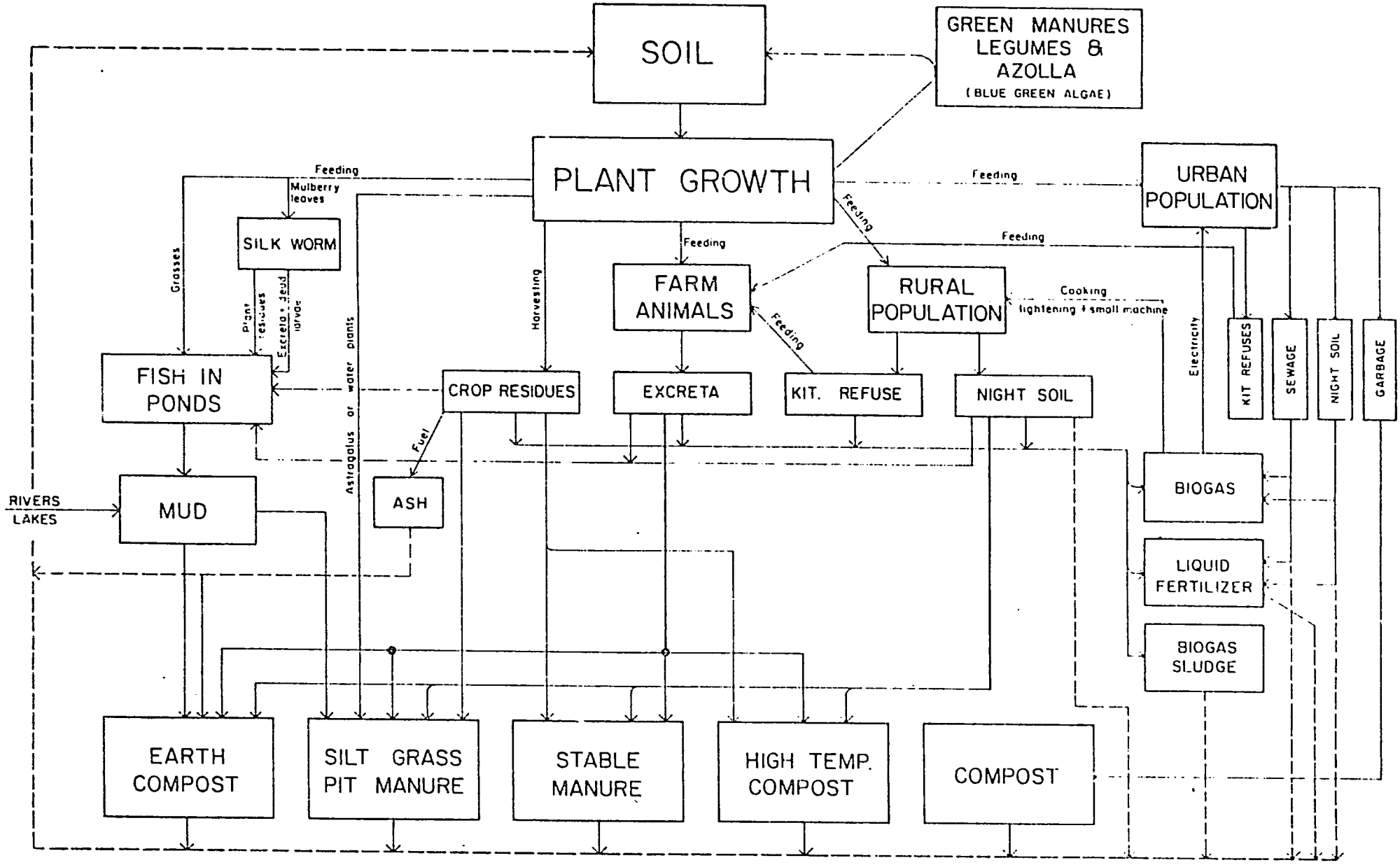
The value of manure as a resource is clear from the estimate that a single pig generates per year sufficient manure to supply fertilizer to increase grain output by 100-150 kg/year (i.e. 20-30 swine produce equivalent of 1 ton/year of ammonium sulfate). Important manurial resources available locally for recycling and use are (FAO, 1977):

- o animal wastes: cattle dung, urine and pig excreta;
- o human habitation wastes: night soil, urine, sewage/sludge, garbage;
- o crop wastes: straw, stalks and stubbles, weeds, grasses, leaves, sugarcane-trash, tea and cotton wastes, (which with the previous two are used in composting);
- o green manures: most commonly Astragatos sinicus (milk vetch), Vicia villosa (hairy vetch), Vicia sativa (common vetch), Sesbania cannabina (sesbamia), Crotalania juncea (sun hemp) and Medicago sativa (alfalfa);
- o aquatic plants: most commonly Alternanthera philoxorides, Pistia stratiotes, Eichhomia crassipes;
- o bio-fertilizers: Azolla pinnata, especially used in fixing nitrogen for rice crops;
- o silt: ammonia nitrogen in silt is reportedly 2-3 times more abundant than in field soil;
- o other resources: including fishwastes, silk wastes, animal bones, oil cakes (by-products from crushing seeds and nuts for oil), ashes, poultry, sheep and goat droppings, industrial wastes.

Figure 9 indicates the highly integrated input/output system that has been developed in China.

Biogas technology has received considerable attention in China primarily because the sludge is richer in nitrogen (120% increase in ammonia, 150% increase in quick acting phosphors) than the corresponding composted manure (producing a 17% increase in wheat yield) (Subramanian, 1978). Although development started in 1958, it has only recently become popular

Figure 9. Recycling of Organic Wastes in the People's Republic of China



Source: FAO, 1977.

with Chairman Mao's assistance in the 1970s. The province of Hebei alone claims 40,000 out of its 56,000 households have small-scale plants (FAO, 1977). Most of the estimated several million plants in China are small scale. Biogas is used extensively for cooking, lighting, fertilizer, and small internal combustion engines. As in India, the widespread use of biogas technology may be attributed to the national policy of introducing such systems.

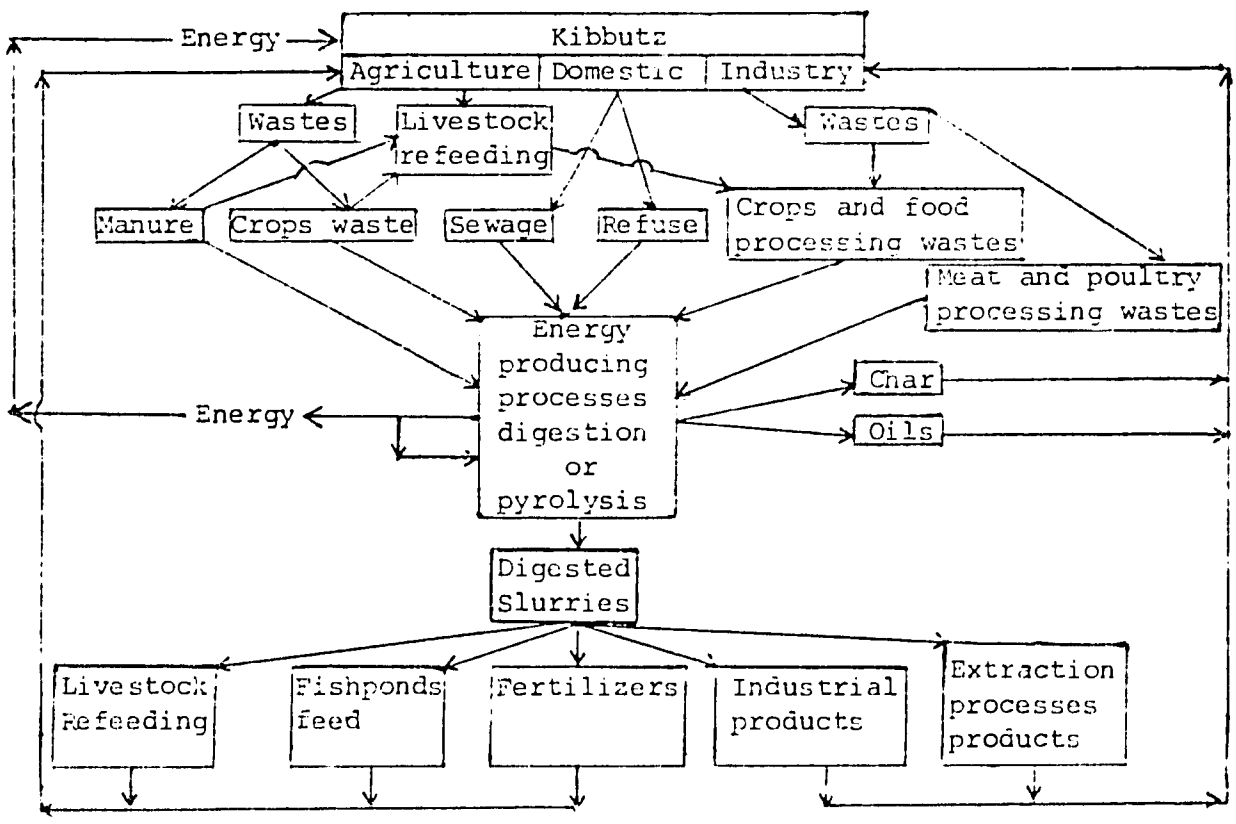
Several examples of larger scale units run on a community basis can be found. The gas from these plants is often converted to electricity for domestic, agricultural and industrial purposes (FAO, 1977). In Fushan City, near Guangzhou, thirty-five digesters ($45m^3$) use cart-collected sewerage to produce electricity and effluent for agriculture. Plastic balloon-type holders are used for storage (two with a capacity of 125 m^3 each). Another example at Pin Niu People's Commune near Changzhou is two interconnected 600 m^3 units fed with ricestraw and wastes from 200 pigs and 40 cows. Gas is used for electricty and distillery operation. Effluent is pumped directly to the fields. Mianyang City, Sichuan Province has two digesters of 174 m^3 and 180 m^3 capacity running on the dung of 30 pigs to produce electricity for small industries such as rice polishing and milling and noodle making. Another plant in Sichuan Province, with a 268 m^3 capacity, is designed to run on wastes from 100 pigs and supply fuel to a milling and husking plant.

Israel. Significant research is reported on Israeli kibbutzes (population 250-2,500) where attempts to utilize the residual streams from agriculture, agro-industrial, commercial, and residential sources are part of a local energy and wastes management system (see Figure 3) (Rousseau

et al., 1979). The research has concentrated largely on developing an inventory of crop residues and improving the efficiency of biogas generation for various waste mixtures. Most of the kibbutzes have large cowsheds (more than 500 head of cattle) and large poultry houses; in addition, most of the northern kibbutzes have fish ponds and most southern ones have large areas of cultivated crops.

As Figure 10 indicates, the wastes streams are processed by either anaerobic digestion or pyrolysis to produce a usable form of energy. The figure also shows that the byproducts or residuals of the energy generation become inputs to other activities. Use of the slurry and sludge of anaerobic digestion as soil conditioner/fertilizer has been widespread, but their alternative uses, such as for livestock or fish feed or as additives to another process (e.g. composting), has been less widely applied.

Figure 10. A Scheme of Agricultural Waste Management in a Kibbutz



Source: Rousseau, I., G. Shelef, and U. Marchaim (1979).

European Countries. The first experiments to collect methane gas in the early 1800s in Germany led to its use to light streets in Exeter, England in the late 1800s. In 1951, 48 small-scale biogas plants in West Germany were used in energy production for municipal power and heating. Several hundred family size installations were put into operation on French farms during the post-World War II energy shortage. Since these projects, biogas research has continued primarily in Germany on large thermophilic plants (96-960 m^3) (Tietjen, 1975). Additional research has been conducted on IRRS components such as aquaculture. Few applications of these studies have been made on community-wide basis.

Japan. Small digesters have operated in the Tohaku region for many years. The rapidly growing Japanese pollution problem and energy crisis have given impetus to research by several institutions working on the anaerobic digestion of rural, urban and industrial wastes. Several large-scale thermophilic units are in operation. Some agricultural use is made of the digested slurry, but findings of toxic ammonium ion accumulations and heavy-metal contamination (primarily from industrial wastes) have made this practice unsuitable for use on some edible plants (Subramanian, 1978).

United States. In the United States, work has primarily been of a theoretical nature or dealt with small-scale applications. Golueke and Oswald (1973) suggest an Algal Regenerative System for single family farms and villages, and have demonstrated the system's individual and integrated operational capacity on the laboratory and pilot scale. They attempt to define a "closed" system -- as far as one could actually approach such a state. Aside from the people and animals, the principal components of the

system are a digester, a series of algal growth chambers, a sedimentation chamber, sand beds, a solar still, and a gas exchanger. The gas generated is used in the residence; digested solids are periodically drawn from the digester for use as a soil conditioner/fertilizer for growing vegetables. The supernatant from the digester enters a pond (the algal growth system), from which water is withdrawn for flush waste in a water closet, and evaporated water is prepared in a solar still for human water use. Golueke and Oswald present the design figures applied in sizing the single family unit and claim that proven satisfactory design data for this unit could be directly extrapolated to fit larger populations. Although the system seems to show great potential for total reuse of residues in tropical areas, its major drawback is the rather substantial capital investment.

The New Alchemy Institute (NAI) (1979) has developed, among other reuse systems, self-sustaining fish ponds for growing high quality protein. Various ponds, ranging from simple to biologically complex, are used. Fresh water is pumped by windmill into the system (500 gal/hour average); outflowing water irrigates the gardens. Algae and fish (White Amur and Tilapia species) are grown in the ponds, which, independently or sequentially over the series of ponds, provide a suitable food chain. Production rates in three months are claimed to be equivalent to what the traditional Chinese polyculture systems produce per year. The water in the ponds functions as a heat reservoir enabling southern or tropical plants to be grown year round. These plants are used as further supplements for fish or human foods.

As poultry and livestock production farms have grown into large mechanized operations, an increased need for management of large volumes of animal wastes has developed. Several large biogas and IRRS facilities are operating in mechanized U.S. dairy and poultry farms. The University of California has developed an integrated sanitation-waste materials recycling system designed to treat wastes, reclaim the nutrients in the wastes and conserve water (Dugan et al, 1972). This system has been implemented on a pilot scale for poultry farm research purposes. Essentially, the system consists of a sedimentation tank, methane digester, and algal pond for the supernatent. A process of algae separation results in both dry algal feed supplement and reuse of the treated effluent for poultry drinking water. The system may be applied to small and large scale system and is economically feasible at $0.01 0.02/dozen eggs. Two large cattle IRRS are utilizing biogas in Brawley, California and Bartow, Florida for 30,000 and 250,000 head of cattle respectively. Both have large scale thermophilic (heated) digesters and scrubbers to purify the methane.

The gas produced is used for heat generation, and boilers for a feed mill plant and meat packing plant. Stabilization ponds further treat the effluent which is reused after treatment for cattle water supply. The slurry, from the Bartow facility is used for reclamation of abandoned mine sites (Diaz and Glaub, 1980). Another project - reported by Diaz and Glaub - operates on urban solid wastes at Pompano Beach, Florida. The system consists of a series of shredders and materials separation procedures feeding into large volume digesters. All three of these facilities report some problems primarily associated with handling the quantity and quality of wastes received.

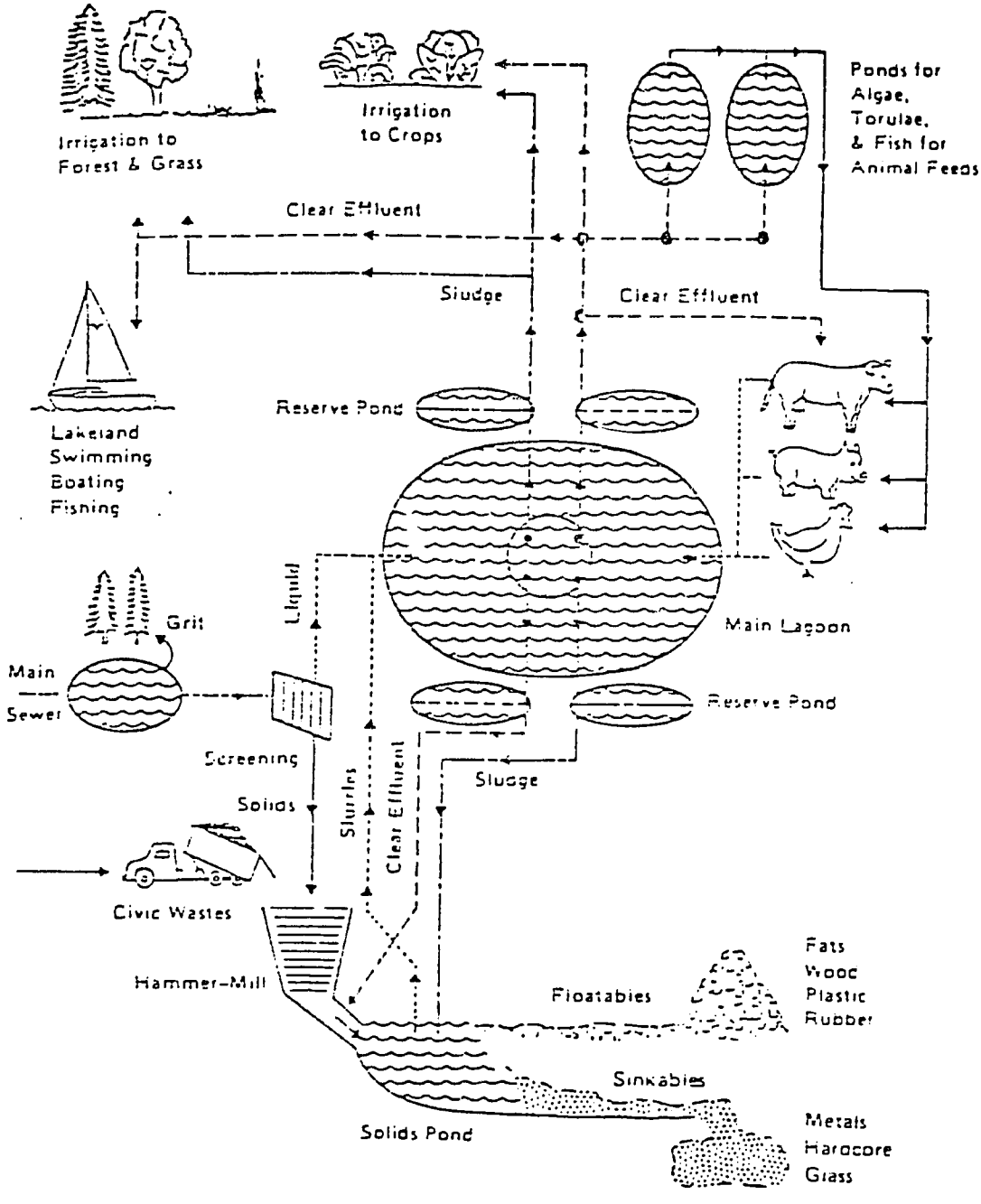
Stanford has developed the concept in integrated waste management systems of regional urban planning around an Agro-Industrial Park or Bio-Industry Center (Stanford 1976, 1978, 1979). He defines the "ring city construct" of regional planning which focuses on establishing population centers with a maximum of 10,000 persons in circular fashion around (and 20-50 km. away from) a central sewage and refuse resource recovery complex, the "agro-industrial park". This design of population centers maximizes reuse of wastes in an efficient manner. The agro-industrial IRRS-channels solid wastes through shredding, separation (for reuse) and treatment processes in a series of pond systems. Sewage is clarified and used in aquaculture systems prior to reuse on agricultural and forest lands; sludge is used as fertilizer/soil conditioner by composting or biogas modes. Figure 11 defines the overall cycles of the bio-industry center.

Implementation of this regional IRRS is underway at two locations in Texas. In central Texas, where a ring of ten cities exists between Dallas (population 2 million) and Houston (population 3 million), local and federal officials are considering establishing an IRRS project to process wastes from Dallas and Houston. This opportunity would allow the ten-city district to regenerate their "farmed-out" soils through recycled resources and export food to Dallas and Houston markets.

The regional plan, which covers three counties, allows for the orderly growth of the ring cities to a maximum population of 10,000,000.

A second implementation of this design is in semi-arid western Texas. The city of Odessa with 80,000 inhabitants is utilizing all their urban resources to restore overgrazed lands surrounding the city.

Figure 11. Bio-industry Center



Source: Stanford (1979).

Stanford (1979) and co-workers have outlined adaptations of this recovery system to several large cities such as Manila and Jakarta in LDCs. Their argument for large centralized waste management complexes is that they will simultaneously solve the multiple problems of food supply, health and environmental problems depletion of fertility in agricultural areas and unemployment facing rapidly growing cities beset with dense populations and inadequate water supply/sanitation systems.

Taiwan. Close to 7,500 small-scale biogas units have been established, generally based on use of the wastes of a dozen hogs. Manual mixing has been effectively developed and the fertilizer value of digested sludge is well recognized. The IRRS which developed here is significantly different because it uses a digester bag (hypalon laminated with neoprene and reinforced with nylon, PVC inlets/outlets), followed by the typical pooling system for alga (*Chlorella*) and fish aquaculture (Subramanian, 1978).

Other Countries

Most other countries have one hundred or fewer small-scale biogas plants and little in the way of IRRS active research; demonstration plants are operating in Pakistan, Bangladesh, Nepal and Sri Lanka. Major obstacles to widespread use of resource recovery technologies include: cost, organization, inacessible and unsuitable terrain and availability of materials (Subramanian, 1978). It is likely that future developments in these countires will necessitate integrated systems and that extensive work, conducted on community level systems in India, China and Israel, for example, will be of much benefit to integrated urban development systems.

V. State-of-the-Art Integrated Resource Recovery Systems

1. Introduction

This section describes the concepts and results of recent work on IRR systems, particularly the work done in Israel. These new developments can be seen as design and technical improvements in the methods of increasing recovery product collection and enhancing growth of the desired biota. The basic goal of the separate component processes described in the previous chapter remains the same for these integrated systems: to provide a favorable environment for the biological transformation of "wastes" to simple organic molecules, mineralized matter and biomass. Because the optimal growth range for the organisms which mediate these transformations is typically a narrow range of environmental conditions, it is important to realize that no matter how sophisticated the design or technical improvements are, intelligent and trained management is necessary for the successful operation of any biological treatment system.

2. Combination of Anaerobic Digestion and Stabilization (Oxidation) Ponds

A very popular wastewater treatment process for almost half a century in developing and in some developed countries has been a series of stabilization ponds. The ponds are usually 1-2.5 m deep and are relatively stagnant. Usually the first pond in the series (when the initial loading is greater than 200-250 kg BOD_5 per hectare per day) is completely anaerobic while the next few ponds in the series are facultative (i.e. only the lower part of the pond cross-section is anaerobic) and the last ponds are almost completely aerobic (with some

dissolved oxygen concentration present in the entire cross-section during most hours of the day).

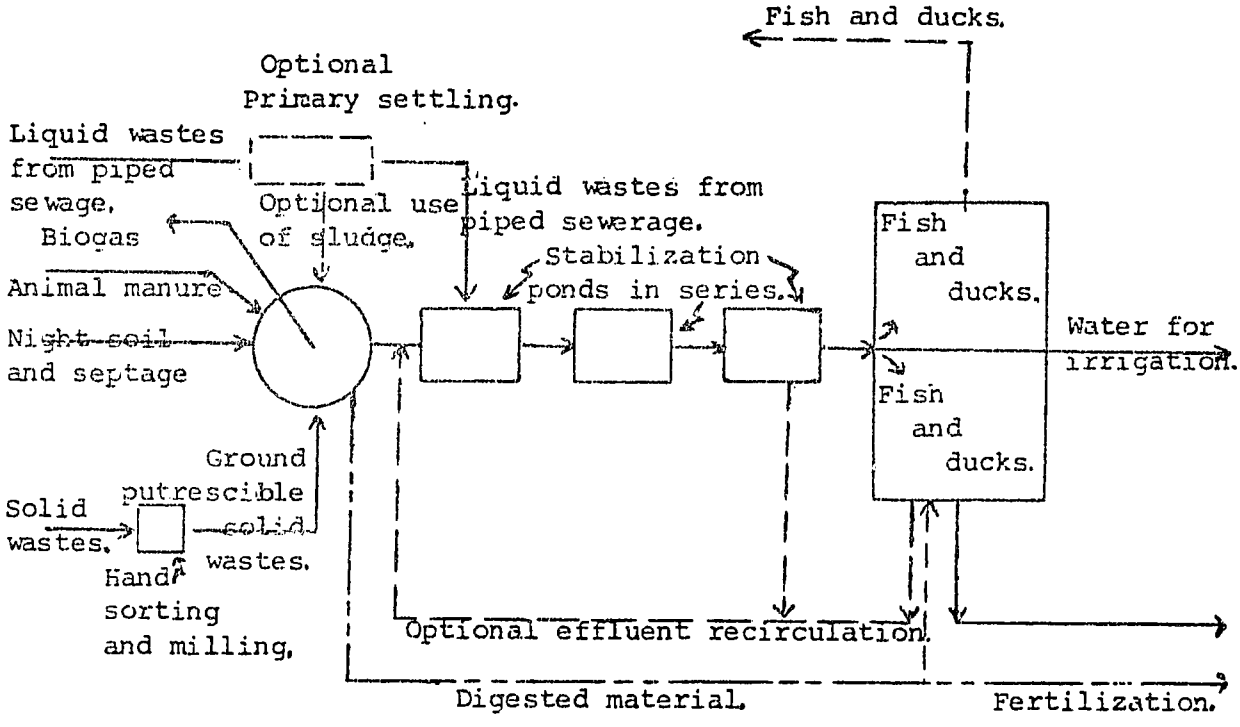
The facultative ponds produce a certain concentration of algae and bacteria in suspension with an average concentration of 50 to 130 mg/l, but this biomass is susceptible to herbivory by rotifers, ciliates, and micro-crustaceans (such as Daphnia, Moina and copepods).

The deficiencies of this system as an integrated solution are: (a) there is no trapping or collection of the biogas as a source of energy; (b) part of the ponds are anaerobic along the entire cross-section and occasionally are a source of malodors and nuisances; and (c) the nutrients and the algal biomass can be recovered only by irrigation or directing the final effluent to a fish and duck farm and not as a direct feed to higher domestic animals.

To overcome some of these deficiencies two modifications of the above system are proposed:

Anaerobic Digestion Followed by a Series of Stabilization Ponds. As shown in Figure 12, an anaerobic closed digestion (which can be divided into a primary and secondary parts) receives the semi-liquid part (night soil, septage and possibly sludge), the animal wastes and the ground putrescible part of the solid wastes (following hand or mechanical sorting and milling). The digester supernatant and the liquid wastes (from the piped sewerage section of twos) are directed into the first stabilization pond in the series. To improve algal biomass production and to reduce the threat of occasional malodors, a recirculation of effulent from the final pond in the series into the first pond is optional.

Figure 12. A schematic layout of an Integrated Treatment/Recovery System Based on a Closed Anaeoribc Digester Followed by a Series of Stabilization Ponds



The effluent from the final stabilization pond, containing a suspension of protein-rich biomass (mostly algae but some bacteria) is fed into the fish and duck ponds with a retention time of 15 to 45 days. The effluent from the fish and duck ponds, which still contains an appreciable concentration of nitrogen and phosphorous, can serve for irrigation. The total retention time for waste in the entire system is between 60 to 120 days (or even more if land is available), thus most of the pathogens are destroyed by this biologically competetive system as well as by sedimentation, solar irradiance, natural destruction, time, and

starvation. There is no need for disinfection of the final effluent even if used for irrigation of fresh produce.

Digested sludge from the anaerobic digester can be used as a high quality fertilizer; part of it can also be used to enrich the fish and duck ponds.

The anaerobic digestion may be run at mesophilic (20-27°C or 33-37°C) or thermophilic (54-57°C) temperature ranges.

The following design parameters can be applied to the various types of digesters (Table 38).

Table 38. Design Parameters of Various Types of Anaerobic Digesters

	Cold Digester Unmixed	Cold Digester Mixed	Mesophilic Mixed	Thermophilic Mixed
Temperature C	20-27	20-27	33-37	54-57
Organic loadings kg volatile per m^3 per day	1.5-4	2-6	4-12	10-22
Retention Period days	40-90	30-60	10-30	6-12
Percent destruction of volatile solids, %	25-45	25-50	28-56	30-50
Expected biogas production m^3 per m^3 of digester volume per day	0.15-0.8	0.2-1.2	1.-2.5	2-4
Expected energy production k cal per m of digester volume per day	900-4500	1200-8000	5500-15,000	10,000-25,000

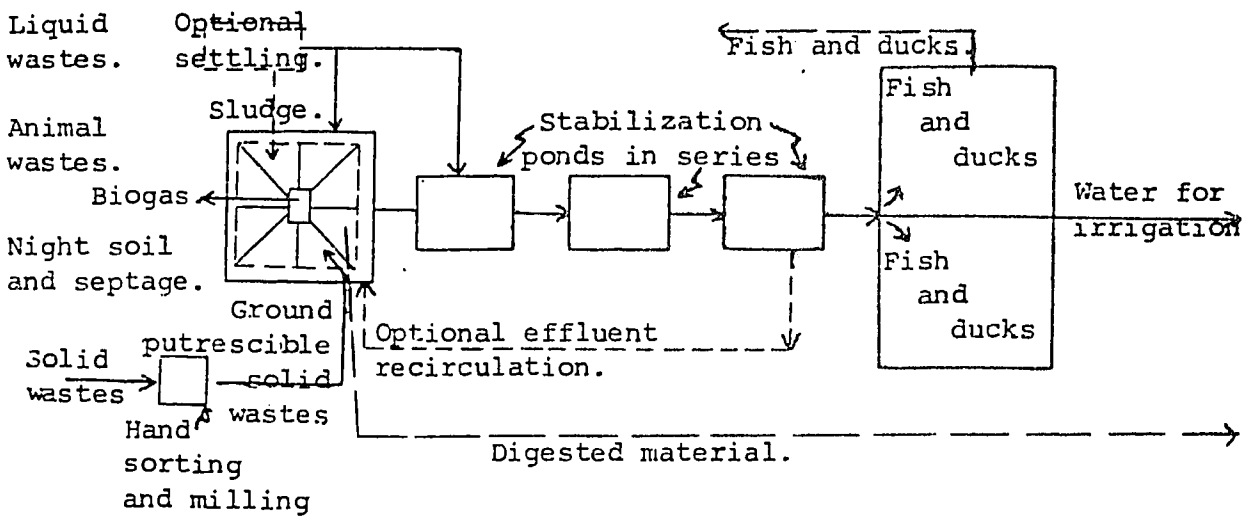
It seems that thermophilic digestion in developing countries might be problematic due to operational and energy reasons although the high temperature can accomplish at least a partial pastuerization of the digester content and thereby improve its health safety with regard to pathogens.

Mesophilic digestion would require the use of a certain part of the biogas for digester heating (depending on the climatic conditions and the degree of digester insulation). Mixing the digester tank can be done by hand, by animal, by wind energy, or by mechancial means. Intermittent mixing is almost as effective as continous. Heating the digester with solar heaters would reduce the need for burning some proportion of the biogas.

Approximately 70 percent reduction of the BOD_5 can be expected in the anaerobic digestion stage. Loadings of up to 160 kg BOD_5 per hectare per day should be maintained over the first facultative stabilization pond in the series to guarantee an aerobic odor-free surface during daytime and part of the night hours. This loading can be increased to 400 kg BOD_5 per hectare per day if recirculation from the last pond to the first pond is maintained at a ratio of 1.5:1. Approximately 30 percent of the dry volatile solids fed to the digester can be recovered as an organic fertilizer containing approximately 8 percent nitrogen and 1.5 percent phosphorus.

<u>Anaerobic Digestion - Stabilization Ponds "Combie"</u>. The Israeli "Combie" design (Shelef 1979) is a modification of the above scheme, in which the first pond is up to 5 m deep and the bottom of the pond is covered by a tent-like biogas collector. This first "combie" pond is followed by a series of stabilization ponds (Figure 13).

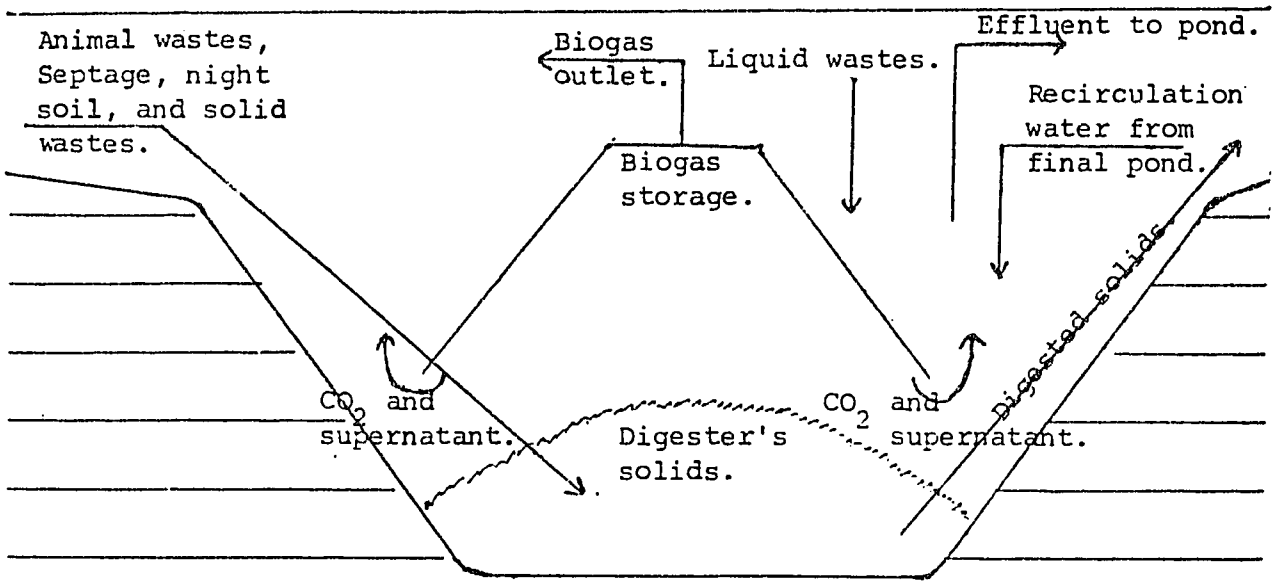
Figure 13. A schematic Layout of an Integrated Treatment/Recovery System based on an Anaerobic Digestion-Stabilization Pond "Combie"



The semi-liquid and solid wastes are introduced below the tent and liquid wastes (from the section of town with piped sewerage) are introduced either over the tent or else into the following stabilization ponds. Recirculation of effluent from the last stabilization pond of the series into the "combie" pond (above the tent) is optional but highly recommended. The anaerobic section can be mixed and even heated or can be left as a cold unmixed digester. The tent can be made of plastic (Figure 14) or other non-corrosive material and should be gas tight.

The "combie" arrangement offers various advantages: (a) substantial reduction in construction and operational costs, (b) carbon dioxide produced by the anaerobic fermentation is used in the upper section where algal photosynthetic production occurs; (c) the CH_4 content of the biogas can reach over 85 percent due to a "water bridge" transfer into the upper algal part and, (d) the upper part provides a slightly alkaline buffer capacity to the lower anaerobic digestion part, thus preventing it from becoming "stuck" by excess acidity (Figure 14).

Figure 14. A schematic cross-section of the "Combie" First Pond (See Figure 8)



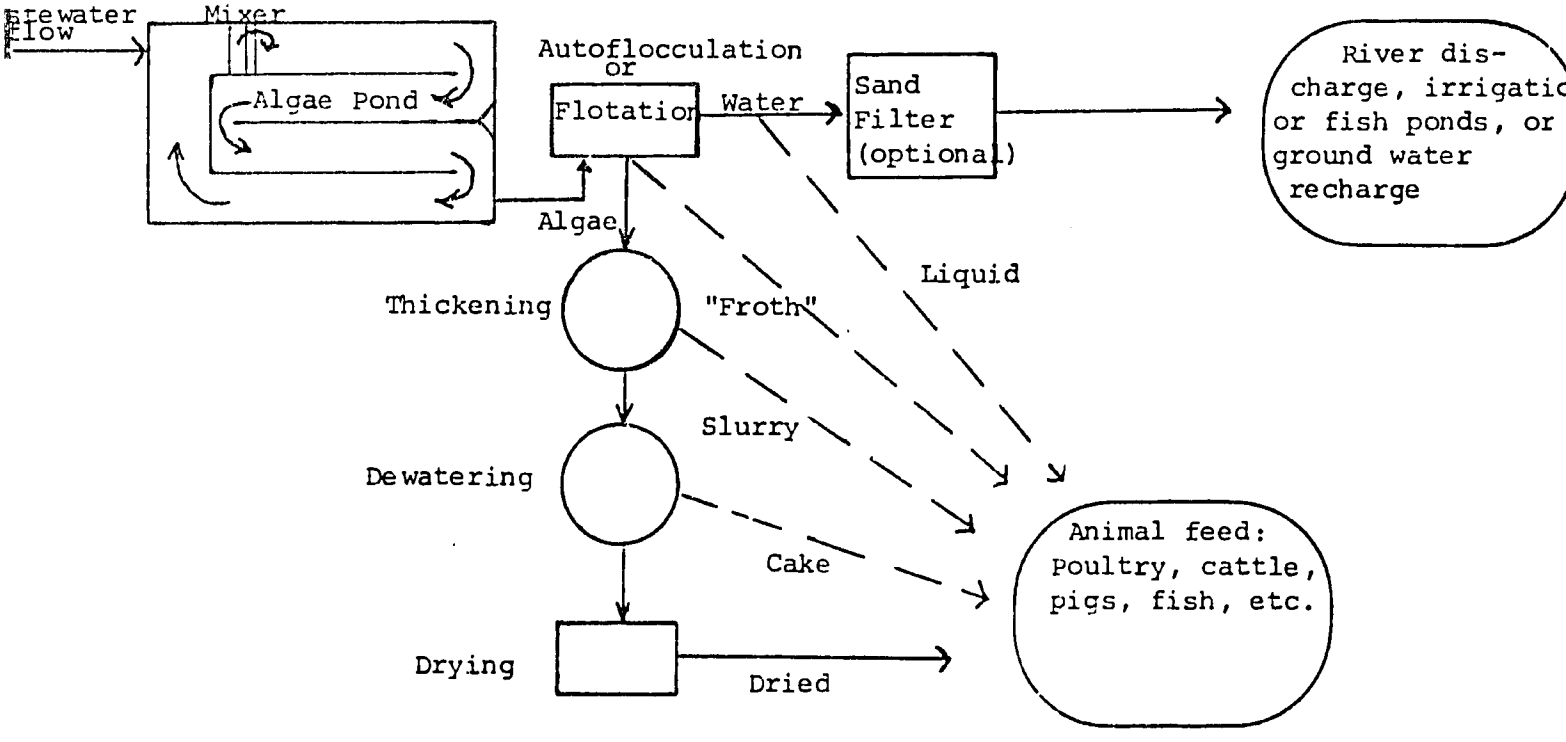
3. Combination of Anaerobic Digestion with High Rate Algal Ponds

High-rate algal ponds have been successfully employed for liquid wastes (municipal, agricultural and some industrial wastes) in developing and developed countries. They are shallow (0.3-0.6 m deep), paddle-wheel mixed meandering channels where an intensive algal-bacterial growth yielding 70 to 160 tons per hectare of dry algal-bacterial biomass (at a mass ratio of approximately 2:1 respectively, with protein content of 35 to 60 percent). Organic surface loading can reach 500-1000 kg BOD_5 per hectare per day and this intensive photosynthesis guarantees the production of enough dissolved oxygen to keep the system's surface aerobic during most hours. Due to the increased loadings and reduced retention time (3 to 15 days) the area requirement is significantly lower than that required by stabilization ponds. The most common species of algae predominanting in

the pond are Scenedesmus, Chlorella, Micractinium, Euglena, Spirulina and Oscillatura, depending on the climatic conditions, bicarbon- ate concentrations and pond operation.

The algae can be separated and dried to prepare a highly proteinaceous food ingredient to chicken, fish, pigs, cattle, and sheep and it can be served to the animals in a wet form or else the algae-containing final effluent can be discharged to fish ponds (Figure 15).

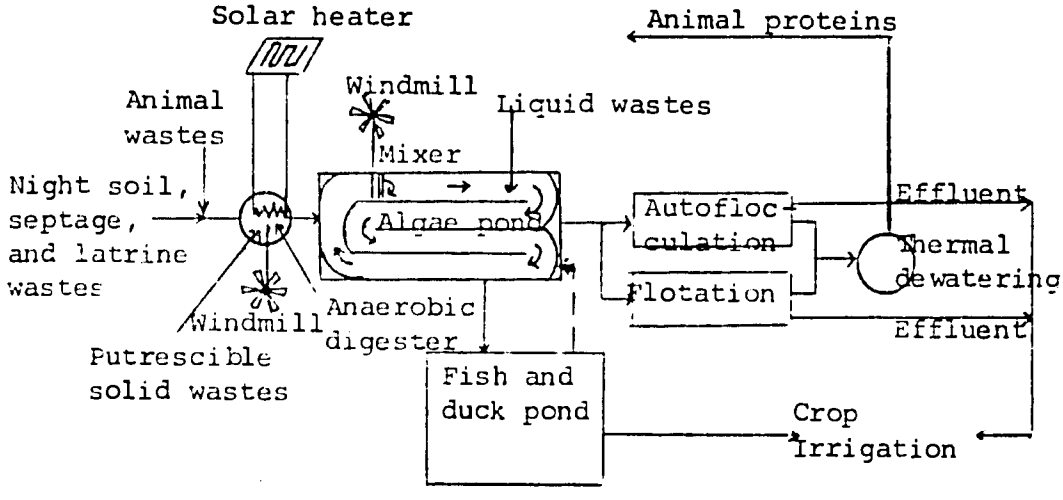
Figure 15. A scheme of High Rate Wasteweater Treatment Process.



With the introduction of concentrated semi-liquid or dry organic wastes into the integrated system, an anaerobic digestion process should preceed the high rate algae production system. Two alternate systems are also proposed.

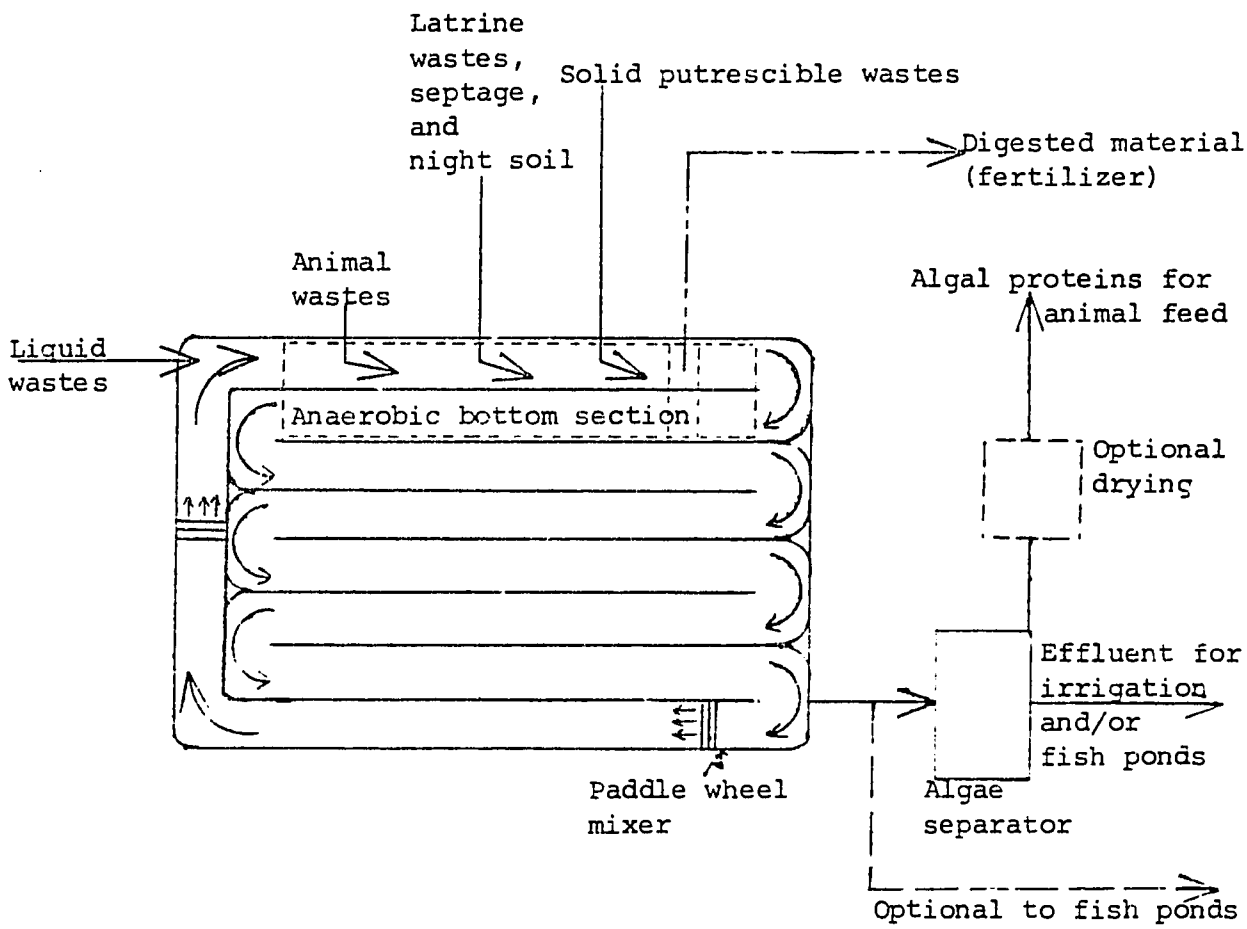
Anaerobic Digestion Followed by Algal High-Rate Pond. Figure 16 illustrates the combination of an anaerobic digestion system with a high rate algal pond system. Algae can be separated by auto-flocculation, by straining or by flotation and can be dried (by solar dryer or by thermal means) or fed to farm animals.

Figure 16. A schematic diagram of an integrated treatement/recovery system based on anaerobic digestion followed by high-rate algal ponds.



Anaerobic Digestion - High Rate Algal Pond "Combie". As shown in Figure 17, this system, developed in Israel by Shelef (1981), combines a high rate pond with an elongated "submerged" anaerobic digester based on the same principle described above.

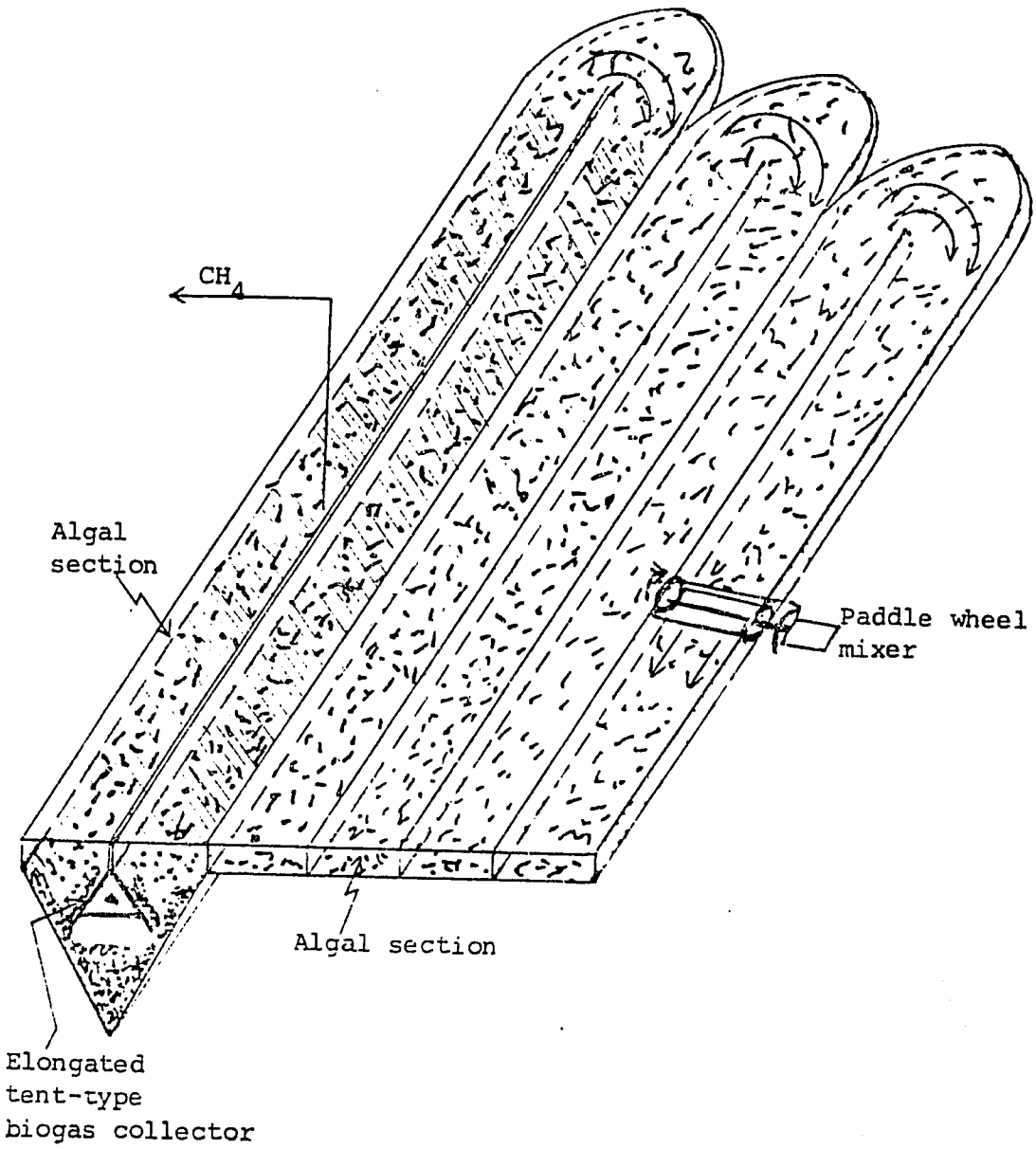
Figure 17. A schematic layout of an Integrated Treatment/Recovery System based on Anaerobic Digestion Algal Pond "Combie"



An elongated tent (Figure 18) separates the anaerobic digester from the high rate pond. The elongated configuration allows bottom reciprocating mixing and, if necessary, hot-water heating.

The increased volume of the digester and the intensified algal photosynthetic activity make this system even more advantageous than the one described in previous sections.

Figure 18. An Isometric and Cross-section Scheme of an Anaerobic Digester-Algal High Rate Pond "Combie" (Shelef 1981)



4. Integrated Treatment/Recovery Systems Which Include Composting

Composting of municipal solid wastes and agricultural wastes (manure and vegetative wastes) has been practiced in developing and developed countries since the thirties. Any biodegradeable organic wastes with a C:N ratio not greater than 40:1 (25:1 being optimal) and moisture content from 50 to 65 percent can be composted provided air circulation is sufficient to provide enough oxygen to the intensive biological aerobic fermentation process. The reaction is a thermophilic one and temperatures within the composting process can reach 63-68° C and higher. The retention time needed to attain complete composting can be as low as 48 hours in fully mechanical plants (such as Dano) and 12 to 30 days in turned-over windraws. Shorter retention time is needed in windraws with mechanical aeration. A period of 15 to 45 days of maturation following the active composting improves compost quality. The thermophilic reaction stretching over a relatively long period provides almost complete pasteurization as far as most pathogens are concerned.

Shuval et al. (1981) gives an interesting discussion of some options for night-soil composting. His report, prepared for the World Bank, emphasizes some of the high technology systems in the U.S. Scaling down the Beltsville aerated Rapid Compost (BARC) system to 10 dry tons per day results in a cost of $51.26 per ton for the compost.

The introduction of dual reversible induced air windows in Israel (Shelef 1978) designed for combined composting of municipal solid wastes and sewage sludges (Figure 19) allowed the total moisture content to reach up to 75 percent; thus, certain quantities of night soil, septage, sludge and other semi-liquid wastes can be introduced into the composting process together with municipal solid wastes and agricultural wastes. Carbon-rich

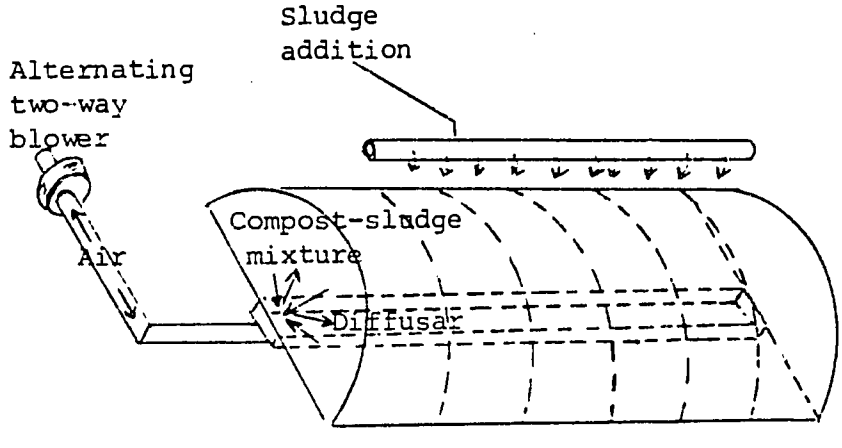
vegetative agricultural wastes such as straw, rice husks and coconut peels can be also introduced, especially when night soil, sludge, septage, latrine wastes and animal wastes provide nitrogen-rich material to maintain an optimal C:N ratio.

The nonbiodegradable part of the solid wastes (such as plastics, glass, metals, etc.), referred to as "rejects", can be used for material recovery and/or incineration (especially of the plastic material with its high caloric value) and the non-usable part can be land-filled.

The main stream of recovered material is the compost which can serve as an excellent humus-type organic fertilizer containing 2-8 percent nitrogen and 0.3-1.2 percent phosphorus. Such compost can be used also to fertilize fish ponds without causing an excessive demand on dissolved oxygen within the pond.

Since the integrated treatment/recovery system assumes that a certain part of the waste stream will be of a liquid consistency (particularly from sections of the town with piped sewerage or very diluted septage) the composting process should be tied in parallel to either a series of stabilization ponds (Figure 20) or an algal high-rate pond (Figure 21).

Figure 19. Schematic cross-section of combined municipal solid wastes - sludge dual induced air window composting system (Shelef et al., 1978).



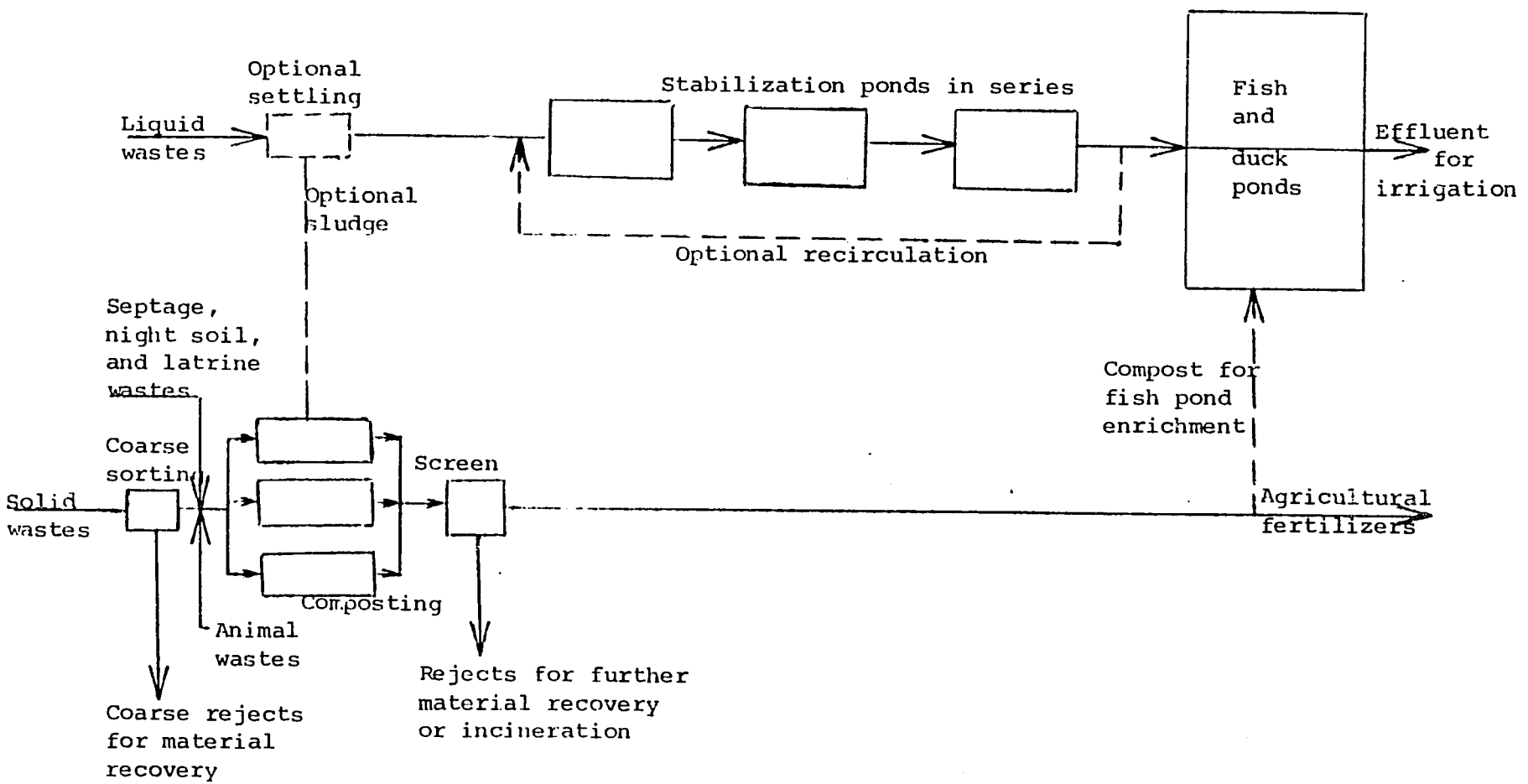
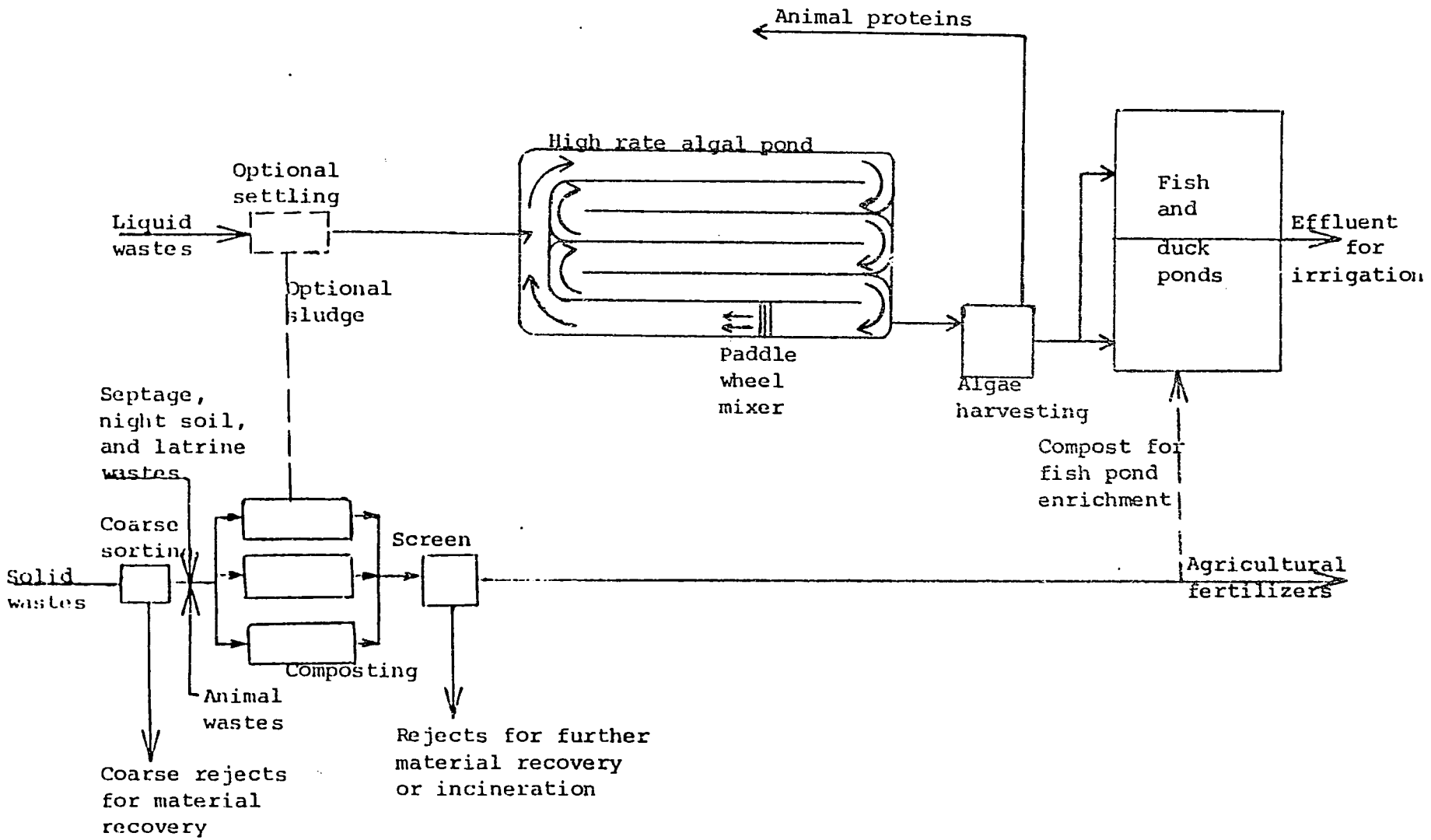


Figure 20. A Schematic Layout of an Integrated Treatment/Recovery System Based on Composting and Stabilization Ponds in Series

Figure 21. Schematic Layout of an Integrated Treatment/Recovery System Based on Composting and High Rate Algal Ponds



The integrated system which is based on composting to solve the problem of the non-liquid wastes should be selected only when the demand for fertilizers and their value is high. Otherwise the integrated system which includes anaerobic digestion should be preferred due to the value of biogas as a source of energy.

5. Recovery Products

Reclaimed Water for Irrigation. It is intended that the final effluents from the above proposed treatment/recovery systems can be used safely for irrigation of most agricultural crops. The long retention time of between 20 to 100 days within rather diverse, competitive biological systems (such as anaerobic, algal-bacterial, fish and duck ponds, etc.) can assure reduction of pathogens by at least five orders of magnitude. Although this might not guarantee the absolute absence of pathogens it still provides an immense improvement and safety component to current situations of irrigating crops with virtually raw sewage or using semi-dried human feces as a fertilizer in many developing countries.

An example for quality requirements of reclaimed wastewater for agricultural irrigation can be drawn from Israel where a severe water shortage coupled with an intensive agriculture, based on irrigated crops, brought about extensive use of reclaimed water for agricultural irrigation.

Table 39 gives the Israeli standards for wastewater effluent quality to be used for agricultural irrigation (ISQW 1978).

Table 39. Effluent Quality Standards for Reuse in Irrigation of Agricultural Crops in Israel (ISQW 1978)

Type of Crop	Group A industrial crops (cotton, sugar beet, etc.), cereals, dry fodder, seeds	Group B green fodder (harvested), olives, peeled fruits, nuts and almonds	Group C deciduous fruits*, cooked vegetables, peeled vegetables, conserved vegetables	Group D unrestricted crops (produce)
BOD_5 total, mg/l	60[1]	45[1]	35	15
BOD_5 dissolved, mg/l	-	-	20	10
Suspended solids, mg/l	50[1]	40[1]	30	15
Dissolved oxygen, mg/l	0.5	0.5	0.5	0.5
Coliforms, total per 100 ml	-	-	250	2.2
Chlorination contact time, min.	-	-	60	120
Residual chlorine (total available) mg/l	-	-	0.15	0.5
Mandatory polishing treatment	-	-	-	sand-filtration
Distance from residential area, m.	300	250	-	-
Distance from paved road, m.	30	25	-	-

[1]Not applied to oxidation pond effluents where most BOD and suspended solids contribution are from algal (secondary) origin.

[2]Irrigation should be under the trees and stopped 15 days before fruit picking: no fruit should be picked from the ground.

Irrigated crops are classified on the basis of public health reasons in four groups, A-D, in an ascending order of the likelihood of transmission of pathogens from the water to humans in the course of consuming the crop.

It should be noted that no specifications have been set for maximal coliform count or minimum residual chlorine level for groups A and B and an exception has been made regarding maximum BOD and suspended solids levels when they are due to secondary biomass, such as algae in the effluent of most pond systems.

The policy of the Israeli Water Authorities is to replace fresh water used in agriculture with reclaimed wastewater and to direct the fresh water to municipal and industrial uses. This policy will exert pressure to prepare the reclaimed water for a less restricted use (Groups C and D), since this will ensure greater flexibility. Following a high rate algal pond or a series of stabilization ponds and sequential fish and duck long-term retention ponds, the quality of the final effluent should be sufficient without chlorination for irrigation of most groups of crops.

VI. Health Considerations

1. Introduction

A major consideration in the implementation of an IRRS is how it will affect the present health conditions of the community. Virtually all studies conducted in the developed countries approach resource recovery systems with the question: what will be the health risks in implementing the proposed system? Evaluations of potential implementation of such projects in LDCs, on the other hand, have a different perspective. The question posed for LDCs is: how will implementation of the proposed system improve existing health conditions relative to the current waste disposal practices? In either case, parallel health risks are involved, but in developed countries the emphasis is on whether non-conventional systems will downgrade existing systems, whereas in LDCs the emphasis is on the economic feasibility of improving health by upgrading sanitation systems through non-conventional means.

Review of the current literature shows that most investigations of pathogen survival and health impacts analyzed only single component systems. No studies have evaluated the overall effects of a multicompon- ent IRRS on pathogen survival and consequent disease transmission. Given the lack of data, it is difficult to assess the specific cumulative effect of each component; such a determination will not be attempted in this report. A World Bank report by Feaehem, et al. (1980) provides the best state-of-the-art review of health aspects of excreta and sullage management.

Another further complication in evaluating the health benefits associated with implementation of the proposed system involves the water-use habits of the community. The proposed IRRS does not account for quality

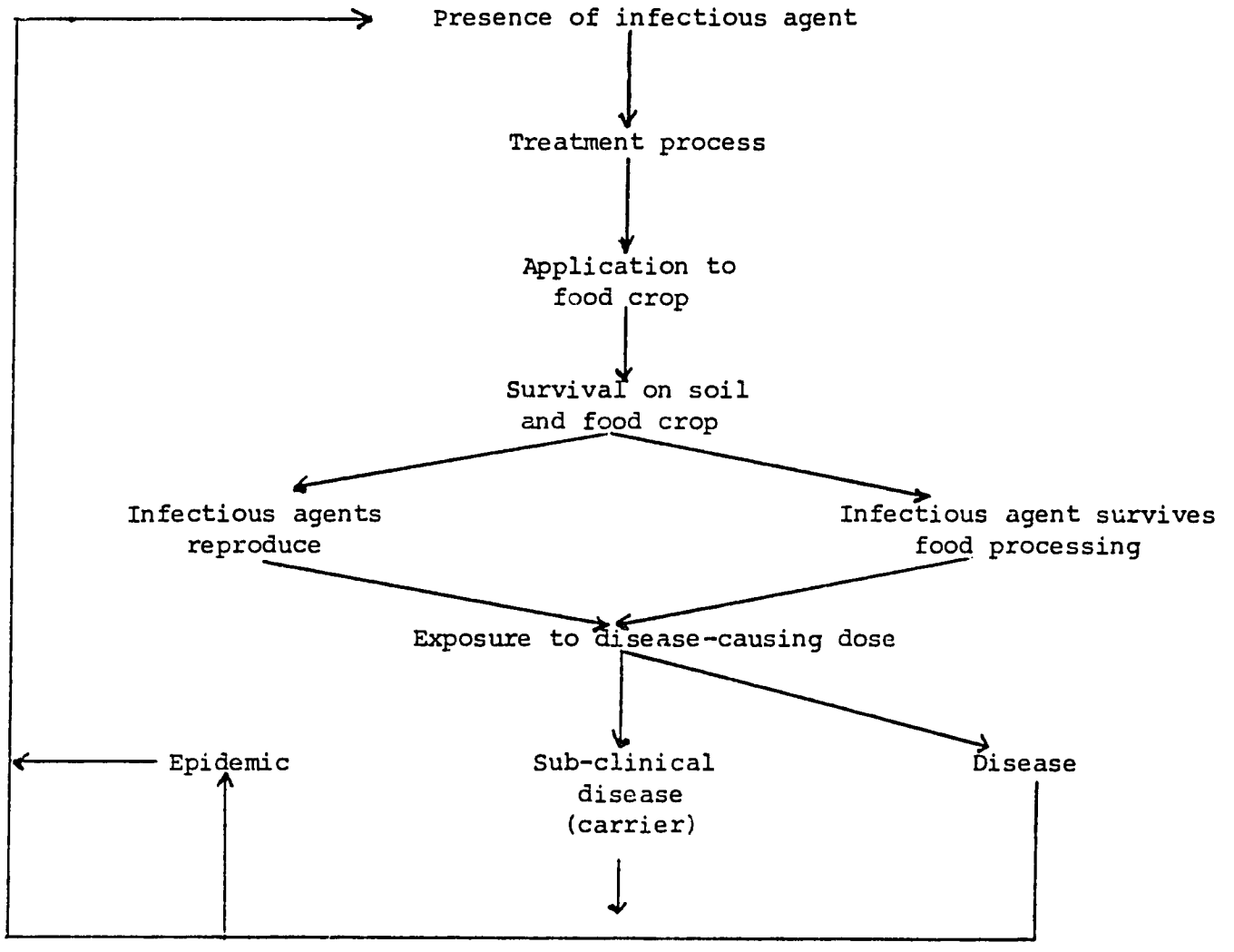
of the original water supply, local water-use habits, recreational water use, or the necessity of water-use education programs. These factors are vitally important inputs to the overall equation which ultimately determines changes in community health.

The predominant factor in determining health risks from sewage sources is the current status of health in the population (Loehr et al., 1979). The routes of disease transmission between wastewater pathogens and humans are long and epidemiologically complex as indicated in Figure 22 (EPA, 1976).

Population groups most likely to be affected by resource waste recovery sites are: 1) those who reside in its vicinity; 2) consumers and handlers of the agricultural produce; 3) recreational users of the sites; and 4) those who operate the facilities. These populations would be exposed to potential infection by pathogenic organisms.

A wide variety of pathogens are present in significant numbers in human wastes. As shown in Table 40, no treatment process (including combinations of conventional and non-conventional treatment) eliminates 100 percent of the pathogens. Wastewaters treated to the secondary level and disinfected with chlorine still contain a range of pathogenic organisms (Sorber et al., 1974; Shuval et al., 1973). Watermeyer (1972) reports the safe use of secondary effluent for irrigation in Rhodesia; while Wellings et al., (1974, 1975) indicate that such use poses a hazard under several environmental conditions. Selected pathogens including bacteria, viruses, parasites (protozoa and worms) and vector insects are shown in Table 41. The table also gives the diseases they can potentially transmit and comparative infective doses for the groups of pathogens

Figure 22. Pathogen Must Overcome Several Barriers



Source: Loehr et al., 1979.

TABLE 40

Percent Removal of Pathogens By Sewage

Treatment Processes

	Trickling Filter	Activated Sludge	Anaerobic Digestion	Chlori-nation
		%		
		Enteric Bacteria		
Total Counts	70-95	70-99	-	96-99
Coliform	82-97	91-98	-	99-99+
Fecal Strep	84-94	-	-	-
Typhoid Group	84-99+	Present: 95-99.2	Not Found 25-92.4	98-99 -
Shigella	-	97-98	-	-
Cholera	-	Not Found	-	-
Micrcbacterium	66-99-	Slight to 87	-	-
Salmonella	84-99+	96-99	-	-
		M. Tuberculosis		
M. Tuberculosis	Survive: 66-99	Survive: 88	Survive: 69-90	Survive: 99+
		Entero Viruses		
Polio	Slight-90+	60-90+	Slight-99+	Slight
Coxsackie	Slight-90+	60-90+	Slight-99+	to
ECHO	Slight-90+	60-90+	Slight-99+	Considerable
Infectious Hepatitis	-	-	-	-
		Parasites		
Tapeworm Ova	18-26	Not Removed	97	No Effect
E. Histolytica Cysts	11-99+	No Reduction	Removed	-
Ascaris Lumbricolides Ova	-	-	45; Reduce	-
Taenia Saginata	62-70	Little Effect	Very Slow	-
Trichuris	-	91.8-100	-	-
Schistosoma Japonicum	Reduced	Excellent Hatching Medium	90 (25-35 days)	-
S. Mansoni	-	-	-	-
Hookworm	100	81.5-96	-	-

Source: Proceedings of the National Conference on Disposal of Residues on Land, 1976.

Table 41.

Selected Common Pathogens of Municipal Wastewaters

Group	Name	Disease(es)	Infective Dose	Comments
Bacteria	Salmonella	typhoid, paratypohid, salmonellosis, gastroenteritis	10^3-10^5	Disease transmission via fecal contamination of food or water; animal's commonly infected by it
	Shigella	shigellosis (bacillary dysentary)	10^1-10^2	Flies can transmit. Growing problem in Central and South America
	Cholera vibrios	cholera - enteropathogenic	10^8	wastewater unlikely to be a source of these pathogens
	Escherichia coli	enteropathogenic	10^8	--
	Mycobacterium		--	--
Virus		viruses produce a large range of diseases		
	polio virus	polio	single	spreads via contaminated wastewater;
enteroviruses	echo virus	variety of diseases; respiratory to central nervous system	virus	pretreatment will eliminate
	cocksackie virus	wide range of diseases	may	--
	hepatitis virus	liver disease	produce disease	hepatitis outbreaks have been linked to ingestion of sewage contaminated food
	adenoviruses	--		--
	reoviruses	--		--
	rotaviruses	--		--
Protozoan	Entamoeba histolytica	amoebic dysentary	≅ 20 cysts	cyst forming, resists treatment, moderate water treatment is effective barrier to spread of disease via protozoa and parasites
	Noegleria gruberi	fatal meningo encephalitis		
	Giardia lamblia	intestinal symptoms		
	Helmintha ova			
Insect	bloodsuckers e.g., mosquitoes, flies	severe annoyance, malaria, encephalitis, typhoid fever, cholera, other gastro-intestinal diseases		adequate drying periods, elimination of standing water "pockets" and use of mosquito fish gambussia are effective methods of reducing vector problem

Compiled from Loehr et al., 1979 and EPA, 1976

(while bacterial infection requires 10^1-10^8 organisms, viral infection requires only a single organism).

2. Pathogen Survival

Pathogen survival in the environment decreases with increased duration of exposure to environmental conditions. Conditions which destroy pathogens over time include (Stowell et al., 1980; Loehr et al, 1979):

- o physical-adsorption, sedimentation, ultraviolet radiation;
- o chemical oxidation, reduction, exposure to toxic substances (some of which are excreted by plants), dessication;
- o biological attack by other organisms, especially native soil bacteria, natural die-off without appropriate host organism.

Each component of the IRRS exposes pathogens to one or more of the above conditions, thus pathogen survival will progressively decrease as wastes are channeled through the system. Some insights into pathogen removal may be gained from a review of the work that has been conducted on individual components.

The capacity of biogas plants to destroy pathogens and parasitic worms has been investigated in a number of studies. An IDRC report from China (Loy, 1976) reported that of the total parasite eggs (including Schistosoma, Ascaris and hookworm) a 94 percent egg removal between influent (23,000 eggs/10 ml) and effluent occurred (1500 eggs/100 ml). Hookworm die-off was both fast and effective. In biogas plants, the reduction of pathogens is due to both physical separation (settling to the bottom of the tank) and to adverse growth conditions. Another experiment evaluating design improvements in the plant's effluent storage chamber and point of effluent removal from the tank resulted in increased parasite egg

reduction from 80% to 98% (Loy, 1976). Other Chinese studies (McGarry, 1977) have indicated that only 6.3% of the original pathogens remained in the effluent. Of the organisms studied, shistosome ova were completely destroyed and few hookworm ova survived. The hardiest egg, ascarid, had remarkable survival capacity, withstanding long periods of severe environmental conditions. The studies concluded that six months is required to ensure die-off of ascarid eggs. Since most biogas plant retention times are less than a month this study recommended the inclusion of a second component in the system such as algal or fish aquaculture, aerobic composting (high heats ensure ascaris destruction) and possibly direct land application to reduce chances of disease transmission. FAO (1977) indicates that the viability of ascarid eggs ranged from 63 to 93 percent after 10 to 90 days decreasing to 20% after 180 days. Other pathogens were observed to survive for shorter periods of time, e.g. para-typhoid B bacilli survived for 44 days and schistosomes lived up to 37 days (see Table 42).

Having achieved significant reduction of pathogens during the biogas phase of the IRRS, the effluent passes through a series of aquaculture lagoons which results in further water purification and destruction of pathogens. Songer et al. (1974) describes a system using raw sewage to culture marine algae and achieves significant reductions in fecal coliforms and enterococci. Apparently Shigella and Salmonella were not detected at any stage of the study. Several studies have documented significant reductions of pathogens in freshwater aquaculture lagoons (Allen and Hepher, 1976). Control of retention time is probably the most effective method of preventing potential pathogen transmission from aquaculture ponds to the final component of the system.

Table 42. Effect of time of digestion on mortality of organisms

Organism	Days of digestion	Percent mortality	Days of digestion	Percent mortality
Snail	20	95.12	32	100.0
Hookworm	50	92.17	90	100.0

Source: FAO, 1977

Digester temperatures above 35°C and detention times of 14 days destroy most vectors (Barnett, 1978); the kill rate for several of these is given in Table 43.

Table 43. Kill rates of pathogens during anaerobic fermentation

Organism - Disease	Temperature (°C)	Retention time (days)	Kill rate (%)
Salmonella spp.	22-37	6-20	82-96
Salmonella typhosa	22-37	6-20	99
Myobacterium tuberculosis	30	n.a.	100
Ascaris lumbricoides	29	15	90
Poliovirus-1	35	2	98.5

Source: Barnett, 1978

Ascaris (roundworm) eggs are an exception to typical pathogen destruction patterns; the major contributing factor to their reduction is physical separation. Percent sedimentation of parasite eggs achieved in Chinese biogas plants is given in Table 44.

Table 44. Sedimentation of parasite eggs in bio-gas plants (in 500 ml of effluent)

	Inlet	Outlet	Sedimentation (%)
Upper stratum	14 039	578	95.96
Lower stratum	50 260	15 695	77.10

Source: FAO, 1977

As discussed in the fish aquaculture section, three modes of pathogenic transmission occur and it is recommended that fish used for direct consumption reside in depuration ponds several weeks prior to harvesting.

3. Land Application

Land application, the final component in the IRRS receives effluent which has undergone multiple stages involving adverse conditions for pathogens. Thus, pathogen survival, though reported in many instances where raw wastewaters are used, should be significantly reduced at this point. Disease transmission has not been documented from any planned, properly managed land treatment system in the United States (usually the sewage is treated and disinfected) (Dunlop, 1968; Loehr et al., 1979; Phillips, 1978). Katznelson et al. (1976) reported on the incidence of enteric diseases in 77 agricultural settlements in Israel in which partially treated wastewater from oxidation ponds was sprayed upon crops without chlorination. The incidence of enteric disease in these settlements was found to be two to four times greater than in 130 communities that did not use spray irrigation. Epidemics have been reported in

instances where raw untreated sewage is applied directly to crops which are consumed raw by humans (Bryan, 1974).

EPA (1976) and Metcalf & Eddy, Inc. (1974), in separate evaluations of land application systems, state that the sources of health risks include the following:

(1) groundwater quality - of particular concern when used as a potable water supply. The most common problem is nitrates. Other sources of contamination such as stable organics, dissolved solids, trace elements and pathogenic bacteria or viruses may occur.

(2) insects and rodents - control of these pests is more important than at conventional treatment sites owing to the increased possibility of pathogen contamination of pests from wastewater.

(3) surface runoff - must be minimized by containment and reapplication to prevent potential health hazards in drainage pathways and surface waters.

(4) aerosols - have the potential for transmission of pathogenic bacteria and viruses through inhalation to the throat and lungs.

(5) crop contamination - depending on the crop usage, different regulations have been established at state and federal levels for crop type and degree of pretreatment required.

Research on the occupational risks to sewage farm workers has produced controversial results. No increased risks were determined when the control group was workers in conventional treatment sites (Bernarde, 1973; Dixon and McCable, 1964). Studies in India which compared the average incidence of infection of sewage farmers with that of a control population not associated with the sewage farms indicate that the former clearly have higher rates of incidence and multiplicity of pathogens (Sastry, 1975; Krishanamoorthi et al., 1973). Crop contamination by pathogens is determined primarily by the crop type and the kind of irrigation practices.

Survival of pathogens on vegetation is of shorter duration than in soils (Kalbermatten, 1980) as indicated in Table 45. The least risk of crop contamination is associated with the irrigation of fiber crops; the greatest risk is associated with food crops, especially those eaten raw (Loehr et al., 1979). Irrigation techniques which avoid direct contact between wastewaters and vegetation decrease the risk of crop contamination (Sadoski et al., 1978). The risk of disease transmission to grazing animals is reduced when a sufficient time interval is allowed between irrigation and grazing. Forage crops dried and stored for at least two weeks prior to consumption produce no health hazard to cattle or human consumers of the meat (Parsons et al., 1975).

Loehr et al. (1979) give the following broadly applicable guidelines for the irrigation of crops with wastewater:

- raw wastewater should not be used for irrigation with spray application.
- raw wastewater may only be applied (without spray) to orchard crops or crops for nonhuman consumption.
- total coliform density should not exceed 5000 MPN* organisms/100 ml irrigation water used for most purposes.
- crops eaten raw should not be irrigated with wastewater unless MPN is below a stated value.
- livestock feed crops should be dried and stored to reduce the possibility of pathogen transmittance.

Aside from crop contamination, pathogen survival in the soils or aerosol sprays are important considerations related to groundwater and habitat contamination.

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*MPN = most probable number -- a statistical approximation of the number of organisms per unit volume of sample.

Table 45. Survival Times of Organisms[1]

Organism	Medium	Type of Application	Survival Time
Ascaris ova[2]	Soil	Sewage	Up to 7 years
	Vegetables	AC[3]	27-35 days
B. Typhosa	Soil	AC	29-70 days
	Vegetables	AC	31 days
Cholera vibrios	Spinach, lettuce	AC	22-29 days
	Non-acid vegetables	AC	2 days
Coliform	Grass	Sewage	14 days
	Tomatoes	Sewage	35 days
Entamoeba histolytica[2]	Vegetables	AC	3 days
	Soil	AC	8 days
Hookworm larvae[2]	Soil	Infected feces	6 weeks
Leptospira	Soil	AC	15-43 days
Polio virus	Polluted water	--	20 days
Salmonella typhi	Radishes	Infected feces	53 days
	Soil	Infected feces	74 days
Shigella	Tomatoes	AC	2-7 days
Tubercle bacilli	Soil	AC	6 months
Typhoid bacilli	Soil	AC	7-40 days

[1]After Pound and Crites, 1973

[2]Unlikely to move in the unsaturated zone

[3]Artificial contamination

Source: Proceedings of the National Conference on Disposal of REsidues on Land, 1976.

Soils. Most enteric pathogens undergo a slow die-off process in the soil matrix owing to both adverse environmental conditions and lack of reproductive capacity. Reduced numbers of pathogens may persist for 2 - 3 months. Filtration by soil at the soil-water interface is the primary way by which bacteria are removed from the wastewater (Loehr et al., 1979). Soils with high clay content remove the maximum number of microorganisms through filtration. Maximum removal efficiency occurs in the upper layers of soil. Movement of microorganisms through soils is directly related to the hydraulic infiltration rate and inversely related to the soil particle size, and concentration/composition of cations in solution (Loehr et al., 1979). Once the microorganisms have been retained in the soils, their survival time varies with pathogen type and environmental conditions. Bacterial survival time increases with neutral and alkaline soils, sterile soils, increased moisture content, decreased temperature, decreased sunlight, and increased organic matter (e.g., greater survival in mulch over sand substrate). Viral survival parallels bacterial survival but the information is sketchy. Sunlight plays an important role in bacterial and viral die-off time. Viruses exhibit colloidal properties and are therefore retained in the soil matrix primarily by adsorption. Factors which influence viral movement in the soils are described in Table 46.

Aerosols. Aerosols (gaseous suspensions of particles in a liquid (0.01-50 m) are susceptible to human inhalation. Sprinkler irrigation of wastewater creates aerosols which contain pathogens. Aerosols containing pathogens are also generated from conventional treatment plants. Pathogen survival time in aerosols varies; high rates of evaporation in aerosols contributes to a high rate of pathogen die-off (Loehr et al., 1979). Other factors which determine the survival of pathogens in aerosols are

Table 46. Factors that Influence the Movement of Viruses in Soil

Factor	Remarks
Rainfall	Viruses retained near the soil surface may be eluted after heavy rainfall because of the establishment of ionic gradients within the soil column.
pH	Low pH favors virus adsorption; high pH results in elution of adsorbed virus.
Soil composition	Viruses are readily adsorbed to clays under appropriate conditions and the higher the clay content of the soil, the greater the expected removal of virus. Sandy loam soils and other soils containing organic matter also are favorable for virus removal. Soils with a low surface area do not achieve good virus removal.
Flowrate	As the flowrate increases, virus removal declines, but flowrates as high as 32 ft/d (9.6 m/d) can result in 99.9% virus removal after travel through 8.2 ft (2.5 m) of sandy loam soil.
Soluble organics	Soluble organic matter competes with viruses for adsorption sites on the soil particles, resulting in decreased virus adsorption or even elution of an already adsorbed virus. Definitive information is still lacking for soil systems.
Cations	The presence of cations ususally enhances the retention of viruses by soil. An increase in valence enhances retention.

Source: Loehr et al., 1979.

described in Table 47. Sorber et al. (1975) have conducted extensive field studies on pathogen survival in aerosols from spray irrigation. Their findings indicate that bacteria can be transported a considerable distance. The two most important factors Sorber found to influence downwind bacterial transport were: (1) the concentration of the organisms at the source; and (2) atmospheric stability (conditions of low wind speed and darkness causing maximum downwind concentration). Other workers have recorded that night irrigation produces ten times the number of aerosolized bacteria than day irrigation (Teltch and Katzenelson, 1978). In addition, a positive correlation between relative humidity and the number of aerosolized viable bacteria has been found by Teltch and Katzenelson, (1978). Sorber concluded that a distance of 1800m is required to reduce the concentration of viable particles to 5 organisms/m^3 air, a level comparable to the background concentrations of organisms in air. A similar distance has been recorded by other workers (Katzenelson et al., 1977).

Insect Vectors. To date, no conclusive evidence has been established which correlated an increase in insect-transmitted disease with resource recovery systems (Loehr et al., 1979). A review of the available literature indicates that more research on this topic is required. Insects can create nuisance conditions and are known vectors of several diseases, therefore population monitoring is recommended (EPA, 1976). Several investigators have shown an increased abundance and diversity of mosquito populations corresponding to increased areas of standing water at land application sites (Parizek et al., 1967). Biological control of mosquito populations can be accomplished by several means which include: (1) addition of fish which prey on mosquisto larvae to aquaculture lagoons, such as *Gambusia affinis* (mosquito fish) and *Lebistes reticulatus* (guppy)

Table 47. Factors that Affect the Survival and Dispersion of Bacteria and Viruses in Wastewater Aerosols

Factor	Remarks
Relative humidity	Bacteria and most enteric viruses survive longer in high relative humidities, such as those occurring during the night. High relative humidity delays droplet evaporation and retards organism die-off.
Wind speed	Low wind speeds reduce biological aerosol transmission.
Sunlight	Ultraviolet radiation is deleterious to microorganisms. The greatest concentration of biological aerosols from wastewater occurs at night.
Temperature	Increased temperature can also reduce the viability of microbial aerosols mainly by accentuating the effects of relative humidity. Pronounced temperature effects do not appear until a temperature of 80°F (26.7°C) is reached.
Open air	It has been observed that bacteria and viruses are inactivated more rapidly when aerosolized and when the captive aerosols are exposed to the open air than when held in the laboratory.

Source: Loehr et al., 1979.

(according to WHO, at least 13 other species are known to have this habit) (Laurence, in Feachen, 1977); (2) control by aquatic plants and algae metabolites in aquaculture lagoons (Amonkar, 1969); (3) elimination of standing water (in particular, warm, shallow pockets which exist for more than a few days) and (4) adequate drying periods between agricultural irrigation.

4. Management Practices to Minimize Health Risks

Many full-scale studies have demonstrated the efficiency of pathogen removal achieved by land treatment systems. Several examples of pathogen removal efficiency are shown in Table 48. However, investigators have pointed out that pathogen detection, particularly viral detection, has not yet been developed to the stage where accurate assessment is possible (Teltch, 1980; Loehr et al., 1979). Factors which promote viral removal by soils should be maximized.

The principal management practices to be considered in the minimization of health risks include:

(i) the degree of preapplication treatment, retention time in irrigation holding ponds. Viraragharan (1969) points out that in addition to minimizing risk to public health, this practice provides for the safe discharge of unneeded irrigation water into water courses;

(ii) identification of pathogens existing in the untreated water of the population, infective doses of those pathogens and routes of potential transmission;

(iii) careful crop selection and restrictions on processing;

(iv) physical factors including proximity to habitations, work and recreation areas, climate and soil characteristics;

Table 48. Pathogen Removal Efficiency

Site Location	Pathogen Type	# organisms/100/ml Initial Conc.	Final Conc.	% Reduction	Distance Percolated	Time	Soil Type	Remarks	Source
Whittier, CA	bacteria	110,000	40,000		.9m, vertical	12 days	-	no bacteria found at greater depths	McGauhey & Krone, 1967
Azusa, CA	bacteria	120,000	6,000		2.1m, vertical		-		McGauhey & Krone, 1967
Lodi, CA	coliform	(see remarks)			2.1m, vertical		sandy loam	concentration decreased below drinking water standards	Gerber, et al., 1975
San Diego, Santee Project	indicator bacteria	(see remarks)	-		60m, horizontal		course gravel & sand	significant removal of bacteria	Loehr, et al., 1979
Phoenix, AZ, Flushing Meadow Project	total coliform		0-200		9m, vertical	2 weeks inundation, 3 weeks drying	fine loamy sand underlain w/ successive layers of coarse sand & gravel		Gerber, et al., 1975
Phoenix, AZ, Flushing Meadow Project	total coliform		5	99.9%	9m, vertical	2-3 days inundation, 3 weeks drying	fine loamy sand underlain w/ successive layers of coarse sand & gravel		Gerber, et al., 1975
Phoenix, AZ, Flushing Meadow Project	total coliform		no detection	99.99%	6m, vertical 3m, horizontal		sandy loam, underlain by coarse sand & gravel	2° effluent, ave. hydraulic loading rate of 90m/yr	Gilbert, et al., 1976
St. Petersburg, FL	polio & echo viruses		detected (see note)		1.5m & 6m		Imokalee sand, no silt/clay	detected at 1.5m; detected at 6m after heavy rainfall; 2° chl. eff.; 5-28 cm/wk	Wellings, et al., 1974
a cypress dome in FL	virus		detected		3m, vertical 7m, horizontal		black muck, sand & clay layers	2° chl. eff.; 5-28 cm/wk	Wellings, et al., 1974

Compiled from: Loehr et al., 1979.

(v) minimization of aerosol transmission of pathogens by establishing vegetated buffer zones (width 15m - 406m, EPA, 1976) and controlling sprinkler application (decreasing nozzle pressure, aim nozzles towards ground, sprinkling only in daylight hours, eliminating sprinkling during high winds);

(vi) dilution of wastewater prior to application;

(vii) termination of application several weeks prior to harvesting; and

(viii) stressing the crops between irrigation periods (Crites, 1974).

According to Kalbermatten (1980), the only treatment systems that result in a pathogen free effluent (i.e., nearly free) are maturation ponds, land application or sand filtration following waste stabilization ponds, or conventional treatment. With sludge and night soil reuse, pathogen-free material results from storage or drying for a minimum of 12 months or thermophilic composting. Since the proposed system integrates the above components (or equivalents of them), it is logical to predict that an end-product which is almost pathogen free will be attained. In conclusion, implementation of such a system would result in a several fold improvement in health conditions directly related to pathogenic organisms of wastewater origin.

VII. Social and Economic Considerations

1. Economies of Scale

Several analysts have conducted evaluations of the economics of small-scale biogas plants in India. In each evaluation, it is emphasized that the benefits of this scale of biogas production are available only to a small percentage of upper class households, comprising five percent of the population (Bhatia, 1977; Bhatia and Niamir, 1979; Cecelski et al., 1979; Ghate, 1979). The major reasons for this are: (1) lack of resources including capital, materials, land, water supply, time, and, in particular, the large number of animals required to operate a plant (Bhatia, 1977, states that 70 to 80 percent of the cattle owners have one to two animals and less than 5 percent have the four cattle required for a small gobar gas unit); (2) investment returns are too low; (3) entrepreneurial skills required to implement, operate and maintain a plant are lacking; and (4) technical assistance, credit, etc. are limited.

The advantages of large-scale community biogas systems over family-size units are well established. They include economies of scale--decreased capital costs (see Table 49), and decreased heat loss and precision required in biogas plant operation. Benefits previously unavailable to the general population include:

- clean fuel for cooking and lighting;
- protein production (from aquaculture);
- increased crops (from biogas fertilization and irrigation);
- potential increases in employment (collection, distribution, and operation and maintenance of the system);

Table 49. Estimates of Capital Costs of Different Plant Sizes

Plant Size	Total Cost (Rs)	Cost per m^3 (Rs)	Total Capacity CFt/Day	Cost By CFt (Rs)	Index
$2m^3$ (household size)	2331.83	1165.92	70	34	100
$8m^3$	5016.54	627.07	283	18	53
$20m^3$	11482.95	574.15	706	16	
$35m^3$	18411.77	526.05	1267	14.5	
$45m^3$	20737.47	460.83	1590	13.5	
$85m^3$	38803.07	456.512	3004	13	
$140m^3$	57952.92	413.95	4948	12	

Notes:

1. Source: Drawings and estimates of Vertical Gobar Gas Plants, Khadi and Village Industries Commission, Bombay, 1977.

2. These costs have since gone up considerably.

3. These costs refer to the KVIC design which includes a steel gas holder. If the costs of newly developed Janata plants (Chinese design) were used, the capital costs for smaller size units (up to 300 cft/day) would be lower by 40 to 50 percent. Although Janata plants of bigger capacities are not available right now, these could always be constructed. For details about Janata bio gas plants, see Bhatia (1979).

Source: Bhatia and Niamir, 1979.

- additional energy (beyond that required for cooking and lighting) available for drinking water systems, irrigation, agricultural processing machines or conversion to fuel/power sources for industrial purposes, diesel engines or electrical appliances;
- concerted community involvement and action.

Subramanian (1978) emphasizes that the main objective of biogas investment should be to distribute income and needs to a wide range of social groups. An IRRS in urban and rural settings is likely to achieve this end with greater efficiency because a larger volume and wider variety of waste products can be used and more beneficial end products result.

However, the economic problems of centralizing the biogas generator are described by Prasad et al. (1974). Building a village biogas digestor might enable those househoulds with fewer than 4 head of cattle to receive benefits from the plant, but the households without cattle or a constant source of dung remain. Should biogas be made available to them and if so, on what basis and in what manner? Prasad et al. (1974) describe three distribution methods: 1) distribute biogas through pipelines; 2) use biogas to produce electricity by generator and then distribute the electricity; 3) store the biogas in transportable containers and distribute them to the villagers.

If the pipeline is greater than 50-100 meters in length, then compressors or booster pumps will be needed due to the low pressure at which biogas is generated (approximately 4 inches of water) (Prasad et al., 1974). In addition, installing a pipeline to each consumer will require skilled personnel and a significant amount of capital. Storage of biogas is difficult since it does not liquify at ambient temperatures. Prasad notes that the steel cylinders necessary for storing pressurized biogas

were not manufactured in India in 1974 and suggests using rubber or plastic balloons for low-pressure storage. The costs of distributing the benefits from a central village biogas generator are difficult to assess but are not negligible.

On a national basis, costs of implementing an integrated resource recovery system with a biogas generator will be offset by savings in imported petroleum feedstocks for mineral fertilizer plants because of the quantity of fertilizer that can be produced by an IRRS (Prasad et al., 1974).

The economic evaluation of an IRRS which incorporates a large biogas unit depends on assumptions made regarding: (i) quantification of output of gas and fertilizer products from wastes used in a biogas system as compared to the fertilizer value derived from composting wastes; (ii) valuation of gas relative to an equivalent heat-yielding quantity of kerosene, electricity or soft coke; (iii) valuation of secondary benefits and costs such as health improvements and increased employment, if quantifiable.

Bhatia's (1977) economic evaluation of biogas plants assumes that the only significant secondary benefit is improved health; in particular he cites decreases in eye diseases caused by cooking smoke. However, he emphasizes that most health improvements are confined to units which have latrines attached. Only 11 to 25 percent of the units studied met this condition; furthermore, the attached latrines were not consistently used. Additional data must be generated before determining the overall economic value of community-based IRRS but preliminary costing from pilot systems indicates positive results.

The scale of community systems in urban and rural communities must be determined on the basis of several factors: location and size of the system according to the density and configuration of residences (to prevent distribution costs from offsetting economies of generation); operational costs depending on the labor and capital costs of gobar and other input collection methods; and effects of increases in gas production per kilogram of input material with larger biogas plants. Although social factors are likely to determine plant size as much as techno-economic considerations, Ghate (1979) recommends that plant sizes should be set at the point where total generation plus distribution costs per unit gas production capacity (or per connection) are lowest. These principles apply equally well to the entire IRRS. In order to make an accurate economic evaluation of IRRS the demand cost or mode of delivery, and price the consumer is willing to pay must be assessed for each reuse product.

Social Considerations

Several social considerations pose the largest constraints to the establishment of IRRS in urban and rural communities. Of primary importance among these is cooperation; in development projects such as water supply systems and latrine programs, it has been shown repeatedly that community enthusiasm, incentive and cooperation are essential prerequisites for implementation, operation and maintenance of a program (Carruthers, 1973; White et al., 1972; Saunders and Warford, 1976; Bhatia and Niamir, 1979). In fact, implementation of the successful biogas community project in Etawah district, Uttar Pradesh, occurred in a community which was socio-economically atypical for India. Every resident is relatively well-off (i.e. landowners with an average acreage of 4.06

hectares versus the national landless average of 26.3 percent), has [illegible] higher education levels than average, is of the same caste [illegible] ds), and lives close together (Bhatia and Niamir, 1979).

As mentioned previously, decisions must be made as to who will receive the benefits from the IRRS. A poor household without any livestock could collect dung from fields and roads (as they do now to fuel their cooking fires) and bring it to the village biogas plant and thereby "earn" their share of generated gas or other benefits. This may not be feasible in residential areas with many houses but no livestock.

Community cooperation is determined to a large extent by social factors such as the caste system and social customs. In India, contact or association with the "bhang" or untouchables caste by members of "higher" casts makes them "polluted" in a religious sense (Cecelski et al., 1979). Thus, in planning the operation and maintenance of an integrated system consideration must be allowed for the degree of cooperation between different castes.

Social customs are critical in determining the acceptance or rejection of a particular system. In the implementation of family biogas systems, psychological and religious objections to the use of human wastes for production of gas for household cooking have been documented in Uttar Pradesh, West Bengal and several other areas. On the other hand, Subramanian (1978) reports "a great willingness to use night soil" in biogas plants in the states of Gujarat and Maharashtra. Interestingly, the use of gobar is widespread owing to the religiously based belief in its cleansing value (Cecelski et al., 1979).

Other social customs which have a significant impact on the effective implementation of IRRS and consequent changes in community health are water use and defecation and urination habits. Direct incentives and public education programs are the most critical consideration affecting these customs. Finally, IRRS require community members capable of careful management to maintain low health risks and organize delivery, retailing, collection, and operation and maintenance of the system (Kalbermatten, 1980). The importance of managers with the incentive and entrepreneurial skills required to manage a product/revenue producing operation successfully cannot be underestimated.

VIII Summary of Tacloban City, Philippines, Field Studies (August-September 1982)

VIII.1 Introduction to Tacloban

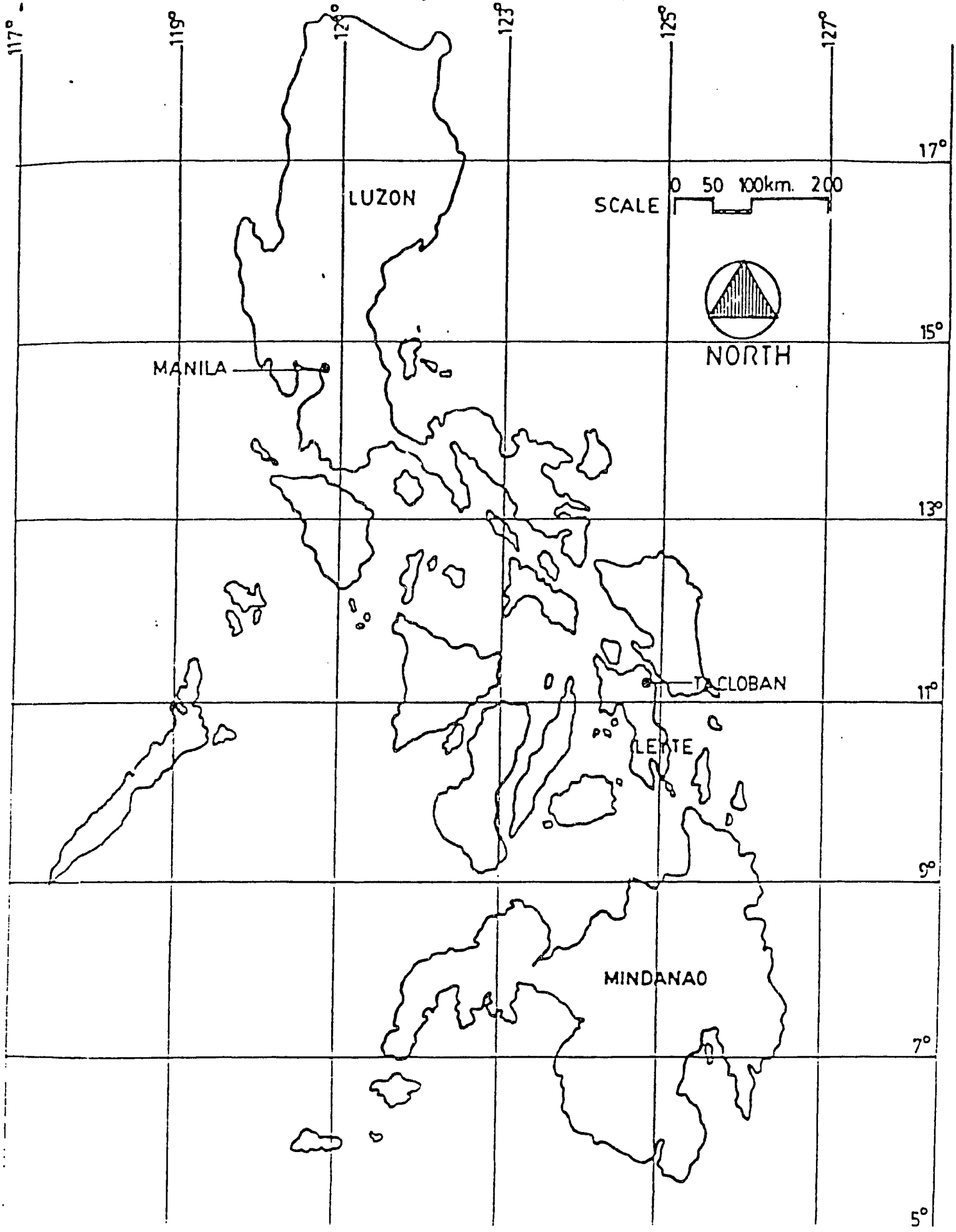
The Office of Urban Development, Bureau of Science and Technology, US Agency for International Development (USAID) under the project, "Managing Energy and Resource Efficient Cities" (MEREC), addressed the problem of increasing the efficiency of small and intermediate size cities in consumption of scarce and costly resources. In order to test various strategies to meet the goals of the project, the city of Tacloban, the Philippines, was chosen as a pre-test site for the global project.

The objective of the MEREC pre-test is to develop (for Tacloban City) a strategy designed to increase the city's efficiency of consumption of important scarce resources. The objective is based on the assumption that the future pattern and nature of development of small- and intermediate-sized cities, such as Tacloban, can be influenced while they are still in the relatively early stages of development and modernization.

During 1981, Meta Systems Inc, of Cambridge, Massachusetts, completed the first phase of its study which was this state-of-the-art study and the second phase was to be a case study of one particular town. For a variety of reasons, the original town chosen was not available. Tacloban was suggested by USAID even though the MEREC project was already well under way at that time. For the purposes of the Meta Systems study, Tacloban was a good location to test some of the ideas about the technical and economic feasibility of integrated resource recovery systems. While reading this chapter it should be remembered, however, that the goals of the MEREC study and the Meta Systems study do not exactly coincide.

The city of Tacloban is located on the island of Leyte, in Eastern Visayas, one of the thirteen administrative and planning regions in the the Philippines. Tacloban City is situated about 360 miles southwest of Manila. Figure 23 shows the location of Tacloban.

Figure 23 . Map of the Republic of the Philippines
Showing Location of Tacloban



The city is composed of 138 political units, known as barangays, 21 of which are located outside the city proper. Tacloban City has a total land area of 10,855 hectares. The city proper covers an area of about 1,770 hectares or approximately 16.32 percent of the total, while the remaining major portion is mostly rural or agricultural land.

The city has a population of 108,433 and as a city, it registered the nation's highest growth rate of 5.6 percent over the past five years. The population was steadily increasing at an average of about 4.1 percent per annum for the last ten years.

Tacloban City is the primary trade center of the region. The National Economic and Development Authority (NEDA), estimated that the city recorded a share of 55.9 percent of the total trade among the five major ports in the region. In 1983, the Philippines Port Authority is planning a multi-million expansion of the Tacloban port to decrease congestion, improve efficiency and accommodate future growth. In terms of income, the National Economic and Development Authority (NEDA) reports that for 1975 the average annual income per household and per capita are P8,908* and P1,457, respectively, an increase of about 86 percent over the 1971 figures for income from all sources.

VIII.2 Current Waste Management Practices in Tacloban

Currently, solid waste is collected in three open dump trucks and covers residences, commercial establishments and institutions such as hospitals and schools. The area covered by the system contains a total population of 70,000 and is divided into three collection areas, with two designated as residential and one classified as commercial. There is no sewer system and the liquid wastes are usually disposed of via the storm/drainage system. The effluents from septic tanks and domestic sewage are allowed to flow into the storm or drainage pipes, provided it passes through a leaching chamber then to a catch basin before entering

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* The exchange rate during August 1982 was P8.43 = US$1.0.

the drainage pipes. Of the estimated 12,040 houses in the city, about 80 percent, or 10,000, have a sanitary toilet, while the remaining 20 percent depend upon unsanitary disposal, including disposal into the sea, rivers and streams. Some human waste is deposited in the waste piles found along the sides of the street.

The average quantity of solid waste based on total number of dump trucks entering the dump site during the present study has been estimated at 22,000 cum. per year. Of the total solid waste disposed, it was observed that about 50 percent is residential, 32 percent commercial, 8 percent street sweepings, 5 percent agricultural and 5 percent other.

Scavenging for materials, such as bottles, cans, cardboard, etc., is commonly practiced at the dumpsite. Scavengers also retrieve materials from storage containers along the street and from the collection vehicles. A small network of material buyers and sellers exists, especially for unbroken bottles. The two dumps in Tacloban in general receive the highly putrescible municipal solid waste in addition to a variety of other wastes such as those originating at hospitals and institutions.

VIII.3 Meta Systems' Solid and Liquid Waste Survey

One of the major problems in developing countries is the lack of data on the composition of the wastestreams for liquid and solid wastes. Since the wastestreams had not been measured in Tacloban, a small comprehensive survey and sampling of waste producing units was conducted in Tacloban to establish the following:

1. kind (quality and quantity) of waste generated; residential versus commercial versus institutional; relationship to income levels, if any;

2. disposal practices and their relationship, if any, to waste characteristics and income levels;

3. difficulties encountered in collecting the wastes;

4. recycling--awareness, needs and attitudes; relationship with income levels, if any;

5. sources, characteristics of liquid waste;

6. disposal practices, problems and awareness of environmental impacts.

The City of Tacloban was divided into 18 subdivisions to cover residential, commercial and institutional (schools, hospitals, etc.) areas. Each subdivision on the average has about 200 houses (not households) and out of this, 50 houses were selected at random.

A questionnaire was prepared to cover the above objectives, and six experienced survey aids from the City Planning Office were assigned the job of interviewing the respondents over a period of five days. Each survey aid was assigned a particular area for observations and interviewing various respondents. These included housemaids (generally on weekdays) and household heads on weekends.

In order to estimate the quantity of wastes generated, various dump trucks were weighed over a period of five days. Care was taken to ensure that the degree of compaction and depth of fill were taken into consideration in the evaluation. The following measurements were taken:

1. The loaded dump truck was unloaded on clean ground and three laborers manually (using shovels, etc.) mixed the contents of the truck and then spread it as uniformly as was practical. From ten different spots selected randomly, almost equal amounts of sample were picked up totaling to a weight of 100 kg (on a weighing machine). This was repeated for commercial, residential, city outskirts, and V & G Subdivision garbage over a period of five consecutive days. The 100 kg samples were sorted manually into various fractions, weighed and percentage calculated. This was carried out under the supervision of the project consultant, city engineer, a trained technician, and four laborers.

2. V & G Subdivision and city outskirts, though both mostly residential areas (90 percent V & G, 80 percent city outskirts), are shown separately for reasons of the use of data in other elements of this study, though the percentages can be shown under residential. The very high percentage of yard waste in V & G

Table 50. Average Daily Weights of Garbage*
(by Location of Origin--Tacloban City)

Origin of Garbage	Average of 2 Days' Collection
Commercial	6883 kg/day
Residential	6777 kg/day
City Outskirts	4615 kg/day
V & G Subdivision **	2900 kg/day

*Data collected during the survey August 3-9, 1982, with assistance of City Planning Office.

**V & G Data (Based on 2 Days' Collection Only).

Subdivision is due to houses with much larger backyards, trees, etc. as compared to those near the city.

3. Quantity. Each dump truck entering the site was weighed over a period of five consecutive days. The number of trips and the origin of garbage was noted. The average daily weights are shown in Table 50.

VIII.4 General Findings of Solid Waste Survey

1. Residential areas contribute more than 60 percent by weight; commercial areas, 30 percent; street sweepings, 3 percent; agricultural wastes, 3 percent; and the remaining 4 percent is a mixture. The exact percentage composition is shown in Table 51.

2. Based upon discussions with the city engineer and General Services Department, it appears that the quantity and quality of wastes varies according to the season and can increase by as much as 30-50 percent during fiesta and school opening season (April-June months). People often engage in renovating their houses during this season. These renovations particularly increase the percentage of nipa* shingles by as much as 100-200 percent. This requires borrowing and temporarily hiring additional manpower.

3. Demolition debris generated is generally disposed of by the building contractors and those engaged in renovating activities (e.g., household heads) and usually in low-lying areas in and around the city or in the surrounding bays. Some of this waste is also left on the streets where it may get picked up by the city garbage collection service.

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*Nipa is a plant--a palm tree--whose leaves can be fabricated into shingles.

**Barangays are small subdivisions in a city. These are generally headed by an elected barangay chairman. Their size can vary significantly.

Table 51. Percentage Comp ..ion of Solid Wastes
(average of five consecutive days)

Type of Waste	Resi-dential	Commer-cial	V&G Sub-division	City Out-skirts	Remarks
1. Yard waste	32.2	29.7	52.0	27.7	
2. Vegetable waste	35.1	22.9	32.4	38.7	
3. Paper	5.5	11.5	5.5	6.2	
4. Plastic containers and bags	3.5	5.5	1.8	2.4	
5. Glass	2.8	4.8	0.5	5.0	Mostly broken bottles and a few others
6. Corrugated cardboard	3.6	4.8	3.6	3.3	
7. Leather	1.5	1.6	-	1.4	
8. Textiles	1.3	3.7	0.4	3.3	
9. Demolition Debris:					
Nipa shingles	0.8	0.8	-	0.8	Made of coconut leaves
Bamboo and wood	2.0	3.8	3.4	1.6	
GI sheets	0.9	0.6	-	1.2	
10. Others:					
Rice husks and ashes	4.5	2.7	-	4.07	
Rubber	1.2	0.2	0.2	-	
Tin cans	2.7	2.8	0.8	3.6	
Dust and stones	0.2	2.6	-	0.81	
Seashell wastes	.06	0.35	-	-	
Coconut husks	1.1	-	-	-	
Scrap iron	0.06	0.31	-	-	

4. Wastes disposed of at the dump site are collected from 102 of the city's 147 barangays** and the V and G Subdivision (a new residential colony). The collection of wastes in some residential areas in the remaining barangays is irregular or even nonexistent. It is assumed that wastes collected from a residential area were generated there (unlike the commercial wastes that could have come from outside the area).

5. Certain inaccuracies in classification of the waste sources are apparent. These discrepancies can occur in situations such as when commercial wastes generated in areas deemed to be predominantly residential were counted as residential wastes; conversely, residential wastes disposed of in containers placed at the markets, or in predominantly commercial areas, get counted as market or commercial wastes. These inaccuracies are considered acceptable, since to correct them would entail major changes in the collection system.

6. Per capita waste generation rates (quantity) could not be classified according to the income level, socio-economic, or separated by barangays because collection vehicles often cover more than one barangay. A collection route often serves both upper and lower income families.

7. Well-packed refuse was found to have a bulk density of 358 kg/cum.; or approximately one-third ton/cum. Based on this bulk density, the total quantity of waste disposed per day amounted to 20,000 kg/day, or equal to 56 cu.m./day.

8. If only the people who utilize the public collection service are considered, the per capita generation of residential and commercial wastes comes to 0.28 kg/day.

9. At present, the solid waste from the three hospitals in the city are not part of the municipal collection. Some schools and

universities generally dispose of their wastes by open or pit burning and/or composting. Their waste generally consists of office scraps, cartons, sawdust (due to current construction activity), broken bottles and plates, used examination booklets, school papers, etc. There is a great deal of scavenging that occurs before any burning takes place. Due to timing and frequency of garbage collection, these institutions are unable to use the city collection services. A change in the city garbage collection schedule would, in view of shortage and frequent breakdowns of dump trucks, be detrimental to other areas.

10. Scavenging.

Scavengers for the purposes of the survey were classified into four groups.

1) "Itinerant Scavengers" travel from house to house and buy material that has been segregated by the householder.

2) "Street Scavengers" are those who retrieve materials from storage containers; they generally sell to scrap dealers in the city.

3) "Collection Crew" also does scavenging and segregates recoverable items from refuse while it is being collected.

4) "Dump site Scavengers" recover materials at the dump sites and pick through the piles with small picks.

From the survey, the following general conclusions regarding scavenging can be drawn:

1) Citywide, almost 72 percent of the people (in 90 percent of the cases the respondent was a housewife) said that if the city starts buying such items as cans and bottles, they would separate them in the households; 8 percent said they would not, while 20 percent had no response. At present it was estimated that no more than 7 percent separate trash themselves.

2) Itinerant scavengers mostly work on the residential streets and at commercial sources. The total number scavenging from the stockpiles or heaps in the city is 100 and approximately 30 scavenge at the dump site. According to the city scrap dealers, their numbers vary significantly and can generally be linked with the market prices of the recoverables these scavengers sell.

3) The exact number and type of scavengers currently operating could not be determined due to time constraints and extreme fluctuations in degree of scavenging. It was mentioned by a Chinese scrap dealer that the current price of crushed tin cans delivered in Cebu (200 miles south) is 60 centavos per kg; hence, there is absolutely no incentive at such a low price. In general in Tacloban, the following factors seem to determine the scavenging activities and/or operation of the system.

- the proximity to materials markets;
- the market value of recyclables;
- the contract provision (if any) between the city and the buyer;
- the disposal costs if the material is not reclaimed;
- the design and the cost of the system; and
- the public participation rate (and frequency).

4) Cans and bottles are used as "flower pots" or as containers for household materials. Leftover food is used as animal food while paper serves as fuel for cooking, as wrapping material or is made into, generally after some pretreatment for softening, toilet paper. About 55 percent of the respondents indicated that they regularly recycle some of these materials (Table 52).

5) About 20 percent save approximately P.7-8 weekly by recycling/reuse. However, about 25 percent indicated that they have no time for salvaging and just leave it to the maid or the city scavengers. The remaining do scavenging on an off-and-on basis, depending upon the availability of salvage.

11. Garbage Storage. Institutions (schools, universities) store their garbage in such items as 200-liter drums, 200-liter half drums, 15-16 liter cans, small plastic grocery bags, abaca (jute) sacks, 1 or 2 concrete communal storage containers located in their vicinity and hand carried, plastic pail, wooden boxes. In

Table 52. Waste Material Reused and Recycled
(each respondent gave more than one answer)

Material	Number (Percentage) of Respondents, N=100	
Cans (used as flower pots, containers, dippers, or sold	45	(45%)
Bottles (used as containers or sold)	38	(38%)
Food leftovers (used as animal food)	28	(28%)
Paper (used as fuel, as wrapping paper, or for toilet purposes)	26	(26%)
Plastics (used as containers)	10	(10%)
Plant debris (used as fertilizer)	7	(7%)
Old shoes, slippers, etc. (used as fuel, sold, or donated)	3	(3%)

some instances, wastes are merely piled adjacent to containers for collection. A major percentage of these waste containers are recycled items.

12. Among the areas served by city garbage collection, according to the survey 65 percent rated the system as good, 18 percent said it was not good, but not very bad, while the remaining 10 percent were not sure. The reasons for dissatisfaction were:

- inadequacy of facilities and manpower as reflected in collection efficiency;
- irregular collection;
- garbage collectors often collect only the garbage they want to collect, and leave the rest; and
- several areas are not being serviced and garbage is stored on site or dumped in the bay.

The majority of the respondents realize the need to dispose of the garbage properly, e.g., 90 percent agreed that plastic bags would be a good idea; however, they were unwilling to buy these on their own.

13. In the vegetable and fish market 85 percent of the vendors do not provide any containers for their wastes. The fish cleaning wastes, exposed (rotted) meat, fruit and vegetable residues are discarded on the floor or behind the stall causing unsanitary, unaesthetic, environmental and public health risks. When questioned each vendor claimed that the wastes belong to the other.

14. It was determined that moisture content on air dried samples approximated 75 percent by weight, which makes the refuse suitable for biodegradation and composting but unsuitable for incineration. This is 3 to 4 times higher than the moisture content of an industrialized city in the Western Hemisphere.

15. Particle size could not be determined for lack of facilities (sieves, etc.). However, it appears to be small.

VIII.5 General Findings of Liquid Waste Survey

1. In the city proper no more than 60-65 percent of the households have septic tanks. Other means of disposal include water sealed toilets, pit privies, direct disposal into the sea, rivers, and streams as well as a few households depositing all of their sanitary wastes on the side streets.

2. Only about 70-80 percent have any kind of sanitary toilets while the rest depend upon unsanitary disposal practices of all kinds.

3. During the survey 95 percent agreed (when explained) with the need for a sewage treatment plant for the city. Among the 95 percent, 25 percent thought the city should pay the entire bill for construction, maintenance, etc., while the rest agreed to share to some extent the cost of operation if it is reasonable and they can afford it. The number of respondents with no answer was insignificant. This showed that the people were aware of the existing situation and need for improvements.

4. The practice of unsanitary waste disposal is more common among shanty dwellers, poor residents, and those living near the Bay.

5. The city storm drainage system also serves as the city sewage system especially for those people with septic tanks. The effluents are dumped into the drainage system. It consists of 10,840 lineal meters of different sizes of reinforced concrete culvert pipes.

6. Efforts were made to determine the chemical and physical properties of the sewage and various effluents at the outfall. However, the existing facilities at the only possible place--the Divine World University are not adequate and would have resulted in unreliable analysis.

7. Only one portion of the city has a centralized sewage collection system with no treatment plant. The effluents are disposed of into the Bay. However, residents near the outlet complain of the odor problems and the waste being deposited in their area. Residents along the mountain side of the city complain of the old drainage system being constantly clogged with mud and earth, thus flooding their area during heavy rainfall. The city engineers' office lacks funds for rectifying the situation.

VIII.6 Prospects for Integrated and Non-Intergrated Resource Recovery Systems in Tacloban

VIII.6.1 Introduction

The original intent of the field study was to attempt to see which, if any, of the integrated and non-integrated resource recovery methods could be appropriate for waste management in a typical middle-sized city in the developing world. The first five chapters of this study, give an exhaustive treatment of all the potential systems. Case studies do tend to concretize the abstract, and Tacloban was no exception. Out of all of the possible integrated systems we concluded that for Tacloban, only one of them--biogas digestion--is likely to be appropriate and acceptable in the next five to ten years. For the non-integrated resource recovery systems, we believe that the current Resource Recovery system for solid wastes could be strengthened, and a small composting pilot plant could be justified. None of the non-integrated liquid waste disposal options that include resource recovery look culturally, socially or economically feasible for Tacloban.

Based upon Table 15, Rogers* predicted the quantities of wastes that should be available in a city like Tacloban and what the ultimate resource recovery potential could be. Table 53 shows the estimates made at that time based upon comparable data from other parts of the world.

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* Rogers, Peter, Seminar at the Divine Word University, Tacloban, July 7, 1982.

Table 53. Hypothetical City of 70,000 Population with No Sewerage System Compared to Tacloban

	Population Served	Per Capita Daily Quantities	Total Tons/ Day	Yearly Total Amount (tons)
Sanitary Wastes:				
Night Soil	21,000 (0)**	1.2 kgpcd	25.2	9204 (0)
Dry Latrines	28,000 (28,500)	0.25 kgpcd	7.0	2556 (2,602)
Black Water (septage)	14,000 (27,500)	14 kgpcd	196.0	71,589 (140,621)
None	7,000 (14,000)			
Solid Wastes		.52 kg/capita/day (.28)		13,295 (7305)
	% Composition			
Food and Vegetable Wastes	68% (65%)		24.75	9,039
$ Paper/Cardboard	7%		2.55	935
Plastics, Leather, rubber	3%		1.09	398
$ Glass and ceramics	2%		0.72	262
$ Rags and textiles	2%		0.72	262
$ Metals (ferrous and non-ferrous)	3%		1.09	398
Misc. combustibles	3%		1.09	398
Cinders, sand, dust, and misc. non-combustibles	12%		4.37	1,596
Total Collectible Solid and Liquid tons/year				96,644 (150,528)

* Items marked with the $ sign are items for which direct separation is attractive because of existing markets.

** Numbers in brackets are those measured or estimated by our survey in Tacloban, August 1982.

On this table, we have also indicated the numbers that we established in the small survey carried out during August 1982. This table allows us to estimate how typical Tacloban is, or is not. Looking at the liquid (sanitary) wastes we see that Tacloban, without a sewerage system and without a night soil collection system, is about typical for dry latrines, lags in the septic tank category and is much worse on unsanitary disposal practices. We were unable to measure the actual amounts of materials in these sanitary wastes. Tacloban appears to be quite low in solid waste generation per capita (about 50 percent of a typical value) even though the food and vegetable wastes component percentages are about exactly as predicted.

Total collectible wastes predicted for Tacloban was a fairly large figure of almost 100,000 tons per year. Based upon the actual observations this figure is expected to be closer to 150,000 tons per year. Rogers* assumed that for complete biogas recovery of all the human wastes, except those with no sanitary facilities, more than 3,000 m^3/day of biogas production could be produced. The putrescible fraction of the solid wastes could produce another 5,000 ^{3}/day of biogas. For the city as a whole, this could amount to meeting the cooking needs of 29,000 people. This could be worth P35,000 per day, in wood purchases avoided. Based upon our survey data, we estimate that about 5,000 m^3/day of biogas could be produced and meet the cooking needs of 16,600 people and be worth P22,000 per day. Of course this figure assumes that complete recovery of all recoverable wastes be carried out. This is a highly unlikely scenario.

The real prospects in Tacloban seem much less optimistic. We conclude that two small biogas plants producing only 30 m^3/day are likely to be taken up in the near future. These plants are to be viewed as demonstration plants to test-out the technology in Tacloban on the local waste streams. Assuming that these plants are successful, it is hard to predict the total size of a concerted biogas program. The main reason for this is the lack of infrastructure for collection of the sanitary wastes, for use as nitrogen

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* Rogers, op. cit.

sources to add to the food and vegetable waste fraction of the collected solid wastes. The size of the biogas program would also depend upon the success of the proposed pilot compost plant. If the compost project demonstrates an economical demand for the compost, then a subsequent expansion of the compost plant would reduce the amount of putrescible material available for biogas production. Similarly, a successful application of biogas using night soil could influence the compost plant.

VIII.6.2 Choices for Integrated Waste Management in Tacloban

Because of the interactions between the various technology options and the various waste streams, it is apparent that a carefully structured decision analysis will be needed once the feasibiity of the options being tested out in Tacloban is locally established. In Figure 24 we have sketched out the waste management currently being practiced in Tacloban. In essence, this looks like a policy of "benign neglect". Only an open dump and some scavenging and resource recovery are practiced for the solid wastes; nothing is done for the sanitary wastes, except to let those that reach the storm sewer system pass through it into the Bay.

In Figure 25, we have overlain the current management practices with the potential options considered for improving the waste management system in Tacloban. In this sketch, we see more complicated interactions of waste streams and technology options than in the current treatment. It should be remembered that Figure 25 does not cover all the potential technology/waste stream interactions, but only those that were deemed to be feasible and appropriate to the City of Tacloban.

Essentially, the choice facing the city government is, as outlined in Figure 26, whether to keep the waste streams separate or to integrate them? Keeping the streams separate, the conventionally chosen option, leads to a variety of decisions about the detailed technologies for treating waste streams. Whichever path is chosen, however, there is currently considerable uncertainty in the decision process. Whether the compost option will produce a product that will have a local market or not, or that the biogas plants will

Figure 24. Current Waste Management Practices in Tacloban

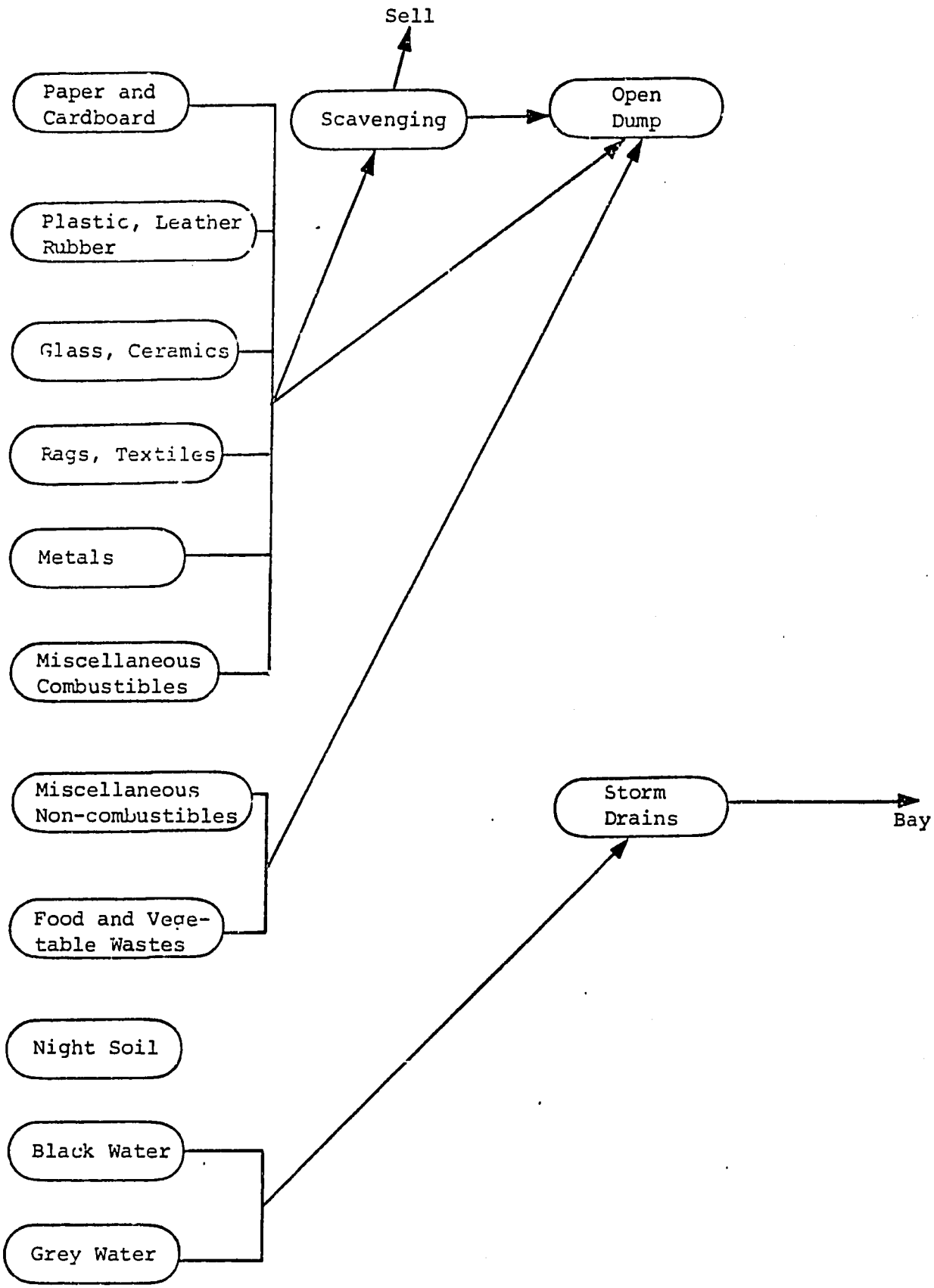


Figure 25. Potential Waste Management Systems for Tacloban

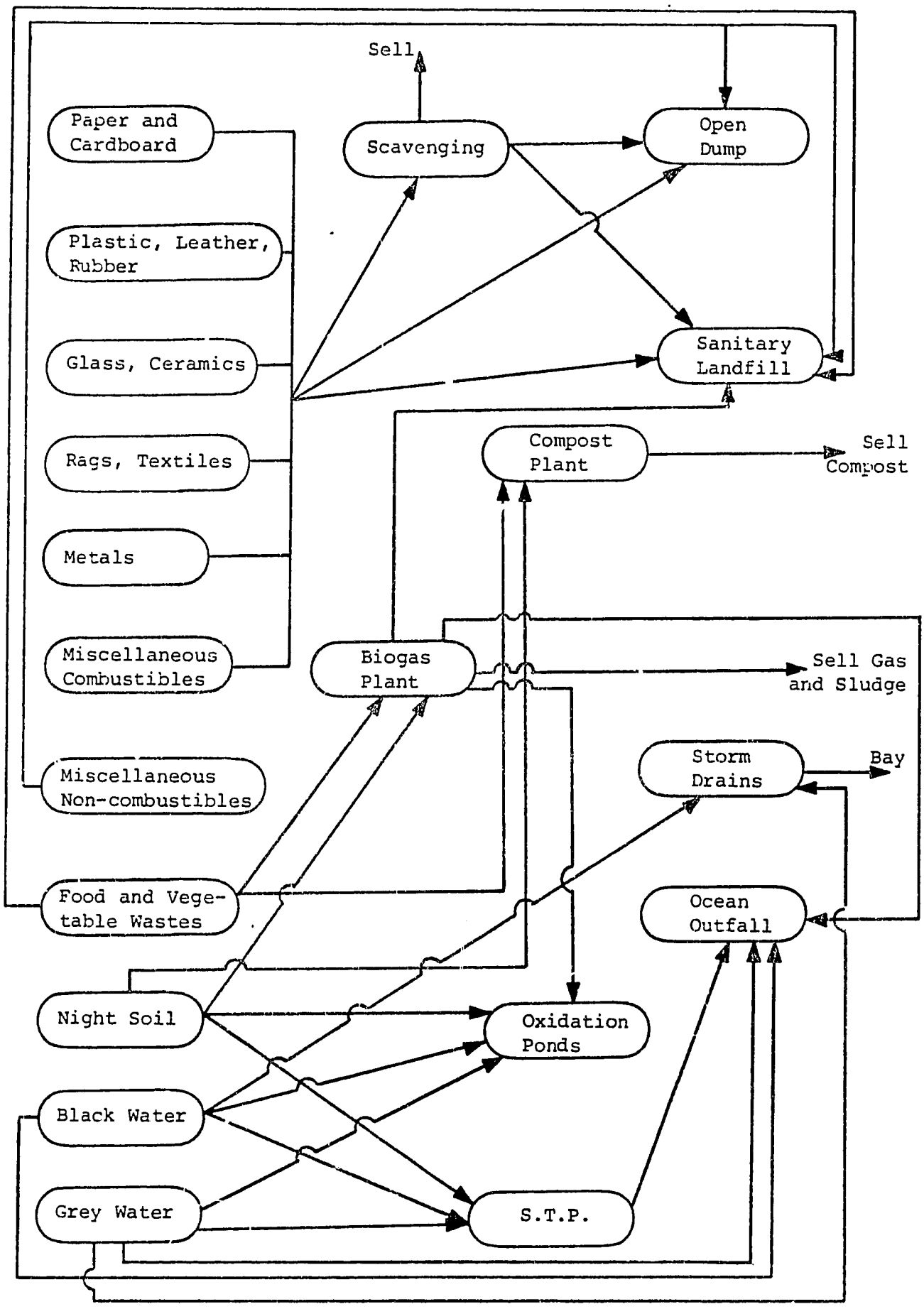
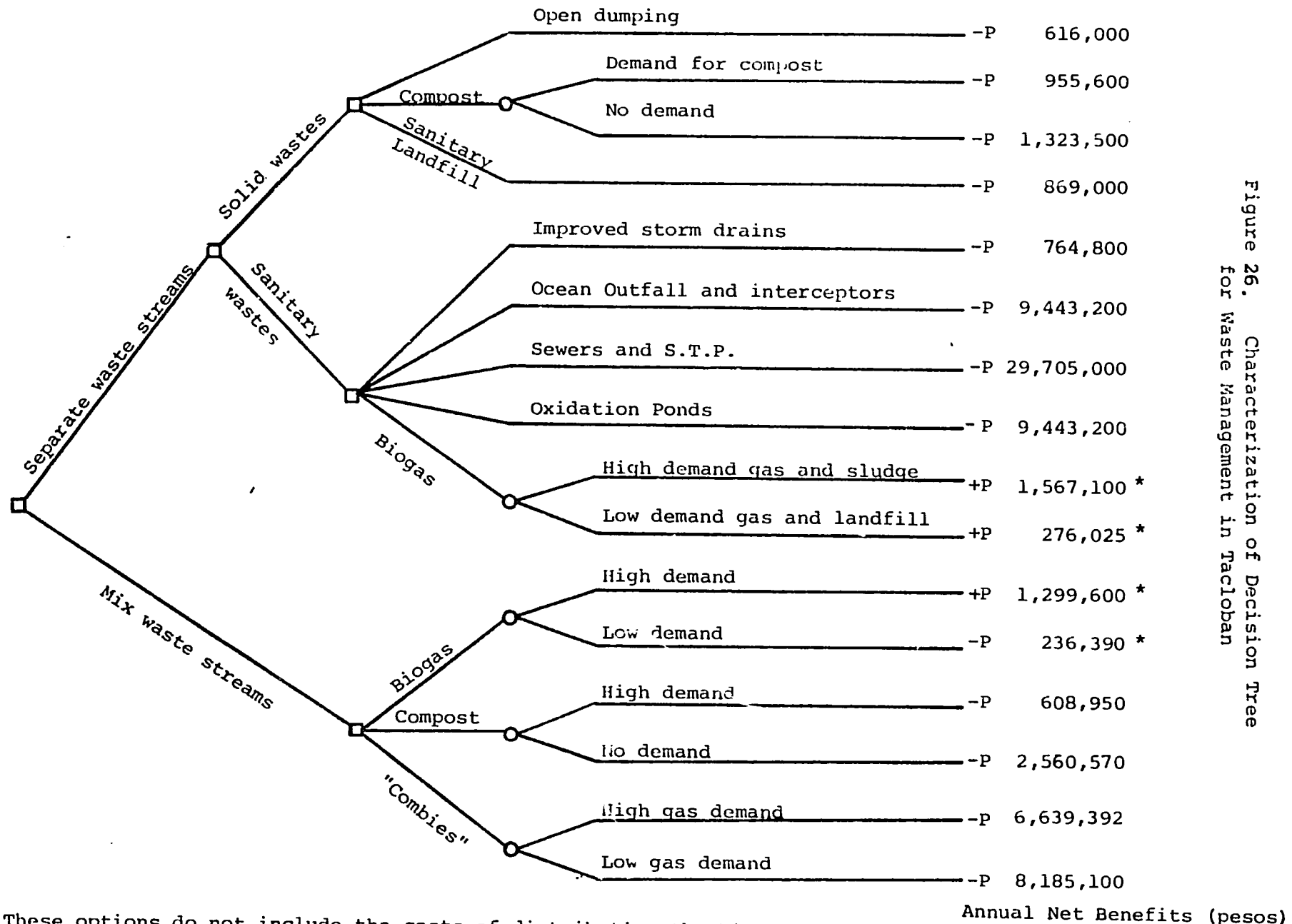


Figure 26. Characterization of Decision Tree for Waste Management in Tacloban



* These options do not include the costs of distributing the biogas to the users. The inclusion of these costs could lead to negative net benefits.

function effectively due to fluctuations on the supply of the human and animal waste products necessary to keep the production at a desired level remain to be seen? In addition, the acceptability of by-products from human wastes remains to be demonstrated. In Figure 26 there are many branches where there is considerable uncertainty about the outcomes, the proposed pilot plants for biogas and for composting will help resolve some of these uncertainties during the next two to three years.

Figure 26 is a bold attempt to pull together all the various parts of our study into one coherent picture. In order to do this, we have had to stretch the limits of the prefeasibility studies made for each of the components. In each case, these studies of the Step 2 Report (Meta Systems 1982)* have dealt with small to medium sized units. In Figure 26, we are considering Tacloban as a whole. Another assuumption that one normally makes with this type of decision-tree in that the outcomes will be roughly equivalent projects, but with differing costs and benefits. This is certainly not true when, for example, one considers open dumping and sanitary landfilling. These give radically different levels of environmental control and with large cost differentials. Nevertheless, we believe it is useful to assay the options in this fashion. For once, the political leadership may be able to get a synoptic view of the available options.

The figures on the ends of the branches represent our best estimates of providing coverage for the whole of Tacloban City proper by the particular technology/waste stream choice. These numbers should be viewed as indications of the relative magnitudes of the costs and benefits and should not be taken too literally. We believe, however, that the ordinal relationships indicated by the numbers are realistic. The numbers themselves, represent the annual net benefits to the city for choosing that particular option.

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* Wastestreams and Integrated Resource Recovery System in Developing Countries Step 2: The application of the State-of-the-Art to Tacloban City, Philippines; prepared for USAID, Contract No. OTR-1406-C-00-1144-00, by Meta Systems Inc, Cambridge, Massachusetts, December 1983.

From Figure 26, we can see that Tacloban's current waste strategy--open dumping and disposal of sanitary wastes to the storm drains--is quite cost effective, even if it is not environmentally sound. The most expensive options for separate wastestreams are, composting for solid wastes, and conventional sewage treatment plant and sewer system for the sanitary wastes. The most expensive of the combined resource recovery systems is that of the "combies" (these are modified oxidation ponds with a built-in continuous flow biogas digester). In each case, the higest cost systems are those that require the construction of sewers, laterals, mains and interceptors. The point emerges clearly from these figures--try to avoid building sewer collection systems.

Some of the technology/stream combinations show positive yearly net benefits. In each case, these are the biogas options. For these calculations, we have assumed a large program of local biogas digestors which would cover the entire city and the use of human wastes as well as other solid wastes in the sytem. This would involve a night soil collection system and the continued disposal of grey water into the storm drainage system. The biogas, moreover, is an untested technology in Tacloban and the benefits could be greatly reduced (as shown on the lower branch of the chance fork) if the sludge has to be landfilled and only 50 percent of the gas could be sold. A major cost which is not charged to the biogas system is the cost of the gas distribution system. If this is included, the biogas option would probably show negative net benefits.

Based upon Figure 26, an experienced and conservative manager could argue for the combined strategy of a sanitary landfill and an ocean outfall as the best management strategy for Tacloban. Both of these technologies are well established and are relatively easy and cheap to operate and maintain with low skilled operators. On the other hand, the potential benefits from a well organized and successful integrated biogas program should certainly lead the city to explore this option fully before reaching any decision on its waste management policies.

VIII.7 Recommendations for Waste Management in Tacloban

Based upon our work in Tacloban, upon our experience elsewhere, and with our review of the State Of The Art of Integrated Waste Management and Resource Recovery we have reached the following conclusions about waste management in Tacloban.

1. Sanitary landfilling is by far the most cost effective of the improved methods for dealing with solid wastes in Tacloban. Assuming no market for the compost, it is exactly one-half the cost per ton of the compost option.

2. If a market were to develop for composting solid wastes, the Indore composting process would probably be cost effective (but still not as cheap as the sanitary land fill option). We recommend that a 3 ton/day pilot plant be built.

3. There seems to be plenty of feedstocks for biogas digestion, the climate is appropriate and there is a lot of experience in the Philippines with similar biogas generators. At least one small pilot community biogas plant should be built, probably at the slaughter house. This pilot plant could build local experience with digestion, design, construction and operations, and would also address the questions of cultural acceptability of this technology.

4. We believe that some form of instream treatment be developed for Mangonbangon River. The oxidation pond that we have investigated looks like an appropriate and cost effective way of coping with the water contamination problems in that part of town.

5. The city should wait for the results of the pilot projects before taking any major decisions on changing its waste management strategies.

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