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ENERGY STANDARDS DIRECTORY FOR THE PROCESS INDUSTRY

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UNITS AND CONVERSION FACTORS

The following units and conversion factors are used in this directory:

Abbreviations and Expressions

kWh = Kilowatthour

toe = tonne of oil equivalent

koe = kilogram of oil equivalent

tce = tonne of coal equivalent

Metric System Multiples

Name	Abbreviation	Multiple
deca	d	10
hecto	h	10^2
kilo	k	10^3
mega	M	10^6
giga	G	10^9
tera	T	10^{12}
peta	P	10^{15}
exa	E	10^{18}

Miscellaneous Conversion Factors

1 Kilocalorie (Kcal) = 3.968 Btu

1 toe = 10^7 kcal = 41.87 Gigajoule (GJ) = 39.7 X 10^6 Btu

1 tce = 6.8 Gcal = 25.4 GJ = 27.10^6 Btu = 0.68 toe

1 kWh (theoretical) = 3,412 Btu = 860 kcal = 0.086 koe

1 kWh (practical)* = 13,650 Btu = 3440 kcal = 0.344 koe

1 tonne = 1000 kg = 2205 lbs.

1 short ton = 2000 lbs. = 0.9072 tonnes

1 long ton = 2240 lbs. = 1.016 tonnes

1 Gigajoule = 238.8 X 10^3 kilocalories

For 1000 kg the abbreviation 1 t is used.

* Assumes 25 percent system efficiency

CHAPTER 1: INTRODUCTION

This directory contains data on energy use standards for industrial products and processes. It can be used by plant engineers and energy analysts to assess the energy efficiency of an industrial plant or to develop targets for efficiency improvements in the industrial sector. The directory has been sponsored by the Office of Energy, Bureau for Science and Technology, United States Agency for International Development, under the Energy Conservation Services Program.

The data presented in this directory are based on a review of the literature on industrial energy use as well as on information from industrial energy audits conducted by RCG/Hagler, Bailly, Inc. The directory will be updated periodically to reflect improvements in industrial energy use efficiency and the availability of more plant-level information. In addition, more industrial processes will be covered in future editions.

Energy standards, of course, must be interpreted with care: international comparisons are often difficult to carry out with precision. Nevertheless, it is hoped that this directory, and subsequent updated editions, will help improve energy efficiency in industrial plants by making useful technical information available to engineers and planners.

1.1 PURPOSE

In recent years, growing energy costs have become a major burden on national economies as well as individual consumers in developing countries. To reduce this burden, many countries are studying energy demand management as a means of reducing energy costs and stimulating economic growth. The experience of developed countries indicates that investments aimed at improving the efficiency of energy use are often extremely attractive and have short pay-back periods.

Of the four major energy-using sectors (industry, electricity generation, transport, households), the industrial sector often presents the best opportunities for improving energy efficiency. Despite efforts to reduce energy waste in the industrial sector, however, developing countries frequently use much more energy per unit of industrial output than industrial countries. One reason is that many developing countries lack sufficient and reliable data on technological developments in industrial countries. In particular, they lack data that would enable them to set goals for improvement in existing processes and to evaluate new technologies in both energy and economic terms. This directory is intended to help fill that gap by publishing figures for energy use per unit of output based on performance in both the industrial world and a wide range of developing countries. In addition, the directory provides brief comments on the key factors that affect energy efficiency in given industrial operations.

When assessing the energy efficiency of a plant, it is interesting to compare the current energy use per unit of output (specific energy consumption) with that of a well-operated

plant using modern, energy-efficient technology. The efficiency of the modern technology is identified as the "norm" or "standard." When assessing the energy performance of an industrial subsector such as the cement industry or steel industry in a developing country, the approach would be similar.

This edition of the directory contains approximately 100 energy standards covering industrial operations that typically account for more than 70 percent of a country's industrial energy use.

The *Energy Standards Directory* will be updated and expanded at regular intervals.. Subsequent editions will be revised based on comments and additional information from users throughout the world.

1.2 PRESENTATION OF THE DIRECTORY

To help the user find the energy standard applying to a given process, standards have been grouped by industrial subsector: cement, steel, chemicals, food, pulp and paper, glass, engineering, construction materials, textiles, and oil refining.

Energy standards are presented as the average energy requirement per unit of output. Wherever data are available, fuel and electricity use are identified separately. The energy unit used in this directory for fuel use is a kilogram of oil equivalent per unit of production (koe/unit)1 and for electricity use, a kilowatt-hour per unit of production (kWh/unit).

These fuel and electricity standards are aggregated in a ratio representing the overall energy intensity of a given process. For the purposes of this directory, electricity use is converted into koe using a conversion factor that represents the true amount of fuel that has to be fired in a conventional thermal power plant to deliver one kilowatt-hour to the end user. An average system efficiency of 25 percent has been assumed, which is equivalent to a conversion factor of 0.344 koe/kWh. This method of conversion provides an estimate of the primary energy that has to be supplied to produce one unit of a given product.

In this directory, energy consumption data are presented for various processes and industrial subsectors. The energy standard for a given product and process is based on the most energy efficient technology available. The gap between the energy performance of a plant and the relevant standard is often an indication of the degree of obsolescence of the equipment or the inefficiency of the plant's operation. The specific energy use in an industrial subsector provides a means of comparing the overall energy use in the industrial subsector of a particular country with that of other selected

1 For standardization purposes, 1 koe is taken to equal 10^4 kilocalories. A slightly different definition may be used in some countries.

countries. A comparison of energy use can also provide an indication of the potential for improvement.

1.3 SOURCES OF DATA

Data used in developing this directory were gathered through an extensive literature search (e.g. national statistics, energy studies on the industrial sector, energy audits) complemented by information from interviews with technical centers, plant engineers, and research centers in the United States and Europe; Appendix A provides a selected bibliography. In addition, information was derived from more than 200 energy audits conducted by RCG/Hagler, Bailly, Inc. throughout the world.

1.4 APPLICATIONS OF THE ENERGY STANDARDS DIRECTORY

Three typical ways in which this directory can be used are as follows:

- Evaluating the relative energy efficiency of an industrial plant
- Assessing the technical potential for improving energy efficiency at the industrial sector level
- Identifying the industrial subsectors that will be the targets for energy efficiency improvement programs.

Application 1: Evaluating the Relative Energy Efficiency of an Industrial Plant

Many plant managers in developing countries, especially in energy-intensive industries, are eager to compare the specific energy consumption of their plant with similar plants in their own and other countries. They may also wish to compare their operating technology with the most energy-efficiency technology available. The directory is designed to facilitate these comparisons. The user can refer to the industrial subsector of interest and find an energy standard for a given product or process, based on good modern practice.

Application 2: Assessing the Technical Potential for Improving Energy Efficiency at the Industrial Subsector Level

The directory user can estimate the potential for energy efficiency improvement by determining the energy savings that could be achieved if all the plants in a developing country were to operate at the level of energy efficiency represented by good modern practice. The technical potential for energy savings can be determined in three steps:

(1) **Collect Data on Industrial Energy Consumption**
This step consists of two components: the analysis of subsector data and

individual plant surveys. Information on energy consumption in selected industrial subsectors can be found, for example, in statistics developed by utilities and oil product distributors. Information on production in physical units is generally available from the relevant Ministry of Industry or the Department of Statistics. Using these data, the directory user can develop a subsector wide table showing sector output and energy consumption for a base year. Individual surveys of large energy-consuming plants will enable the user to study in more detail the links between energy consumption and output for major industrial products in the country. In addition, such surveys may be used to substantiate the energy data obtained from national statistics.

(2) **Collect Data on International Energy Standards**
Energy standards for a given product and process can be found in this directory. The user must be cautious in collecting data on international standards since the industrial structure or processes involved can vary from country to country.

(3) **Estimate the Technical Potential**
The actual energy consumption by product or subsector, derived in Step (1) can be compared with the consumption based on the energy standards used in Step (2). Comparisons should be made for both fuel and electricity.

Owing to data limitations, using this approach to determine technical potential generally covers only a few of products within any given industrial subsector. It does not, therefore, provide total energy consumption in a subsector. To estimate the energy efficiency of a subsector, the directory user must calculate weighted-average specific energy consumption based on the specific energy consumption of identified products, using the total energy consumption for each product as a weighting factor. The potential for improving energy efficiency at the subsector level can then be estimated from the difference between the weighted-average specific energy consumption and the weighted average based on the energy standards. Provided over 70 percent of subsector energy consumption is represented by the products examined, this method may be used with reasonable confidence to evaluate subsector energy efficiency.

Application 3: Targeting Industrial Subsectors for Industrial Energy Efficiency Improvement Programs

Two important items are important when targeting industrial subsectors for an energy conservation program: the relative energy efficiency (in terms of specific energy consumption) and the energy saving potential.

The relative energy efficiency is expressed as the ratio of the specific energy consumption to the corresponding energy standard. Although, strictly speaking, this applies to an industrial product, the same concept can be used for a subsector, using the

10

weighted averages described in the approach to assessing the savings potential. In most cases, it is reasonable to assume that a poor relative energy performance means there are opportunities for low-cost or high-return conservation measures, and that benefits can be expected within the short term. If relative energy performance is good, on the other hand, the investment required to improve energy efficiency is likely to have a relatively long pay-back time.

The energy savings potential consists of the decrease in energy demand that would result from operating a given subsector with a specific energy consumption equal to the energy standard. This potential is a measure of the likely impact of an energy conservation program. Generally, the implementation cost of an energy conservation program must be balanced by energy savings that are large enough to provide an acceptable return on the investment.

The choice of subsectors for conservation programs depends on an analysis of the relative energy performance and the energy savings potential, as well as such country-specific factors as the economic performance of the various subsectors and their competitive position.

1.5 LIMITATIONS OF THE APPLICATION OF ENERGY STANDARDS

Energy standards are technical ratios. There are limitations to their application and the directory user should be aware of these.

1.5.1 Factors Responsible for Differences in Energy Efficiency

The difference between plant performance and the corresponding standard can result from a combination of many factors, including:

- the process used
- the extent of heat integration practiced within the process
- the use of cooling water or cooling air
- climatic factors
- characteristics and quality of raw materials
- recirculation of product (internal and external)
- final product specifications
- plant size

- disposal (or value) of byproducts
- training and competence of plant operators
- operating practices and standards of maintenance
- competence of supervision and management
- operating schedule (e.g. two-shift versus continuous operation, five or six days versus seven days a week)
- level of plant automation and control instrumentation provided
- capacity utilization (e.g. as percentage of maximum throughput)
- environmental standards
- choice of fuels, extent of electricity use.

The directory user must thus take great care when comparing the specific energy consumption of plants; full details of the process, raw materials, and final products are often not known. Provided care is taken in interpreting such comparisons, useful conclusions can be drawn. However, rigorous quantitative calculations cannot be made with absolute certainty until comprehensive plant data are available.

1.5.2 Industrial Process-Specific

Energy standards are associated with a manufactured product and with a process. For example, a wet-process cement plant has a different energy standard than a dry-process cement plant. Steelmaking can use the open hearth or basic oxygen process, with quite different specific energy consumptions. When making comparisons between plants, great care must be taken to ensure that similar processes are being compared.

1.5.3 Energy System-Specific

An energy standard is not only associated with a product and a process but also with an energy system designed to supply the heat and power required by the process. Energy systems can vary in design from one country to another, and yet be efficient. The design of an energy system depends on the local availability and pricing of energy used for fuel and electricity. In some countries economics and regulatory considerations may encourage the use of cogeneration systems (which do not find favor in all countries).

1.5.4 Process Heat Integration

The extent of heat integration within a plant can have a substantial effect on overall energy consumption. Using the latest techniques of "pinch technology," energy savings of 30-40 percent can be achieved in plants whose technology was believed to be the most efficient by the conventional design standards of the late 1970s or early 1980s. In many plants, it is now practical to determine the thermodynamic minimum energy consumption (based on first and second law applications) and to develop a program aimed at realizing this minimum by retrofit measures with attractive paybacks.

1.5.5 Nonprocess Energy Use

Nonprocess energy use such as air conditioning, building heating, ventilation, lighting, and transportation is normally considered to account for a small share of industrial energy consumption (below 10 percent). This nonprocess energy use may differ from one country to another as a result of climatic or social conditions. The directory user should be aware of this and take it into account as far as possible. However, as the standards are derived from existing plants, they do not include this non-process energy use to the extent normal for the United States, N.W. Europe, and Japan.

1.5.6 Use of Energy Sources as Feedstock

In some chemical and metallurgical processes, energy sources are used also as feedstock (e.g. coal, coke, natural gas, oil products). Directory users should take this factor into account when making comparisons.

1.5.7 Energy Consumption and Capacity Utilization

The energy standards are based on the assumption that all equipment is operated at its nominal capacity. However, substantial changes in specific energy consumption can occur when a process is operated below capacity.

In those factories where output can be expressed in terms of one major product, a great deal can be revealed about the efficiency of the process by plotting energy use against production rate. A typical graph plotting two components [energy related to production (mP) and energy not related to production (e)] is shown in Exhibit 1.a, where the variables are defined as follows:

E = Total energy
e = Energy not related to production
P = Production rate
m = Gradient
mP = Energy related to production

For example, in a simple factory using only electricity, "mP" could be the electricity used to operate machines, while "e" could be the electricity used for various purposes that are not directly related to production, such a lighting, ventilation fans, and air conditioning.

If there were no such nonproduction "services," all the energy used would be directly related to production, shown in Exhibit 1.b. At the extreme, a very inefficient factory might use almost the same amount of energy, whether or not production is high or low (Exhibit 1.c). Examination of the graph of energy against production reveals the energy used for "services" or standing losses from equipment, in contrast to the energy actually used for production.

An item that is often monitored by plant managers is the "specific energy consumption" (SEC), which is the energy used per unit of output:

$$SEC = E/P$$

For the typical factory, performance is given by:

$$SEC = E/P = e/P + m$$

A plot of SEC against production rate (P) is shown in Exhibit 1.d. The characteristic curve shows that energy efficiency, as measured by the energy consumed per unit of output, will generally decrease as throughput falls.

Exhibit 1.a

Energy versus Production

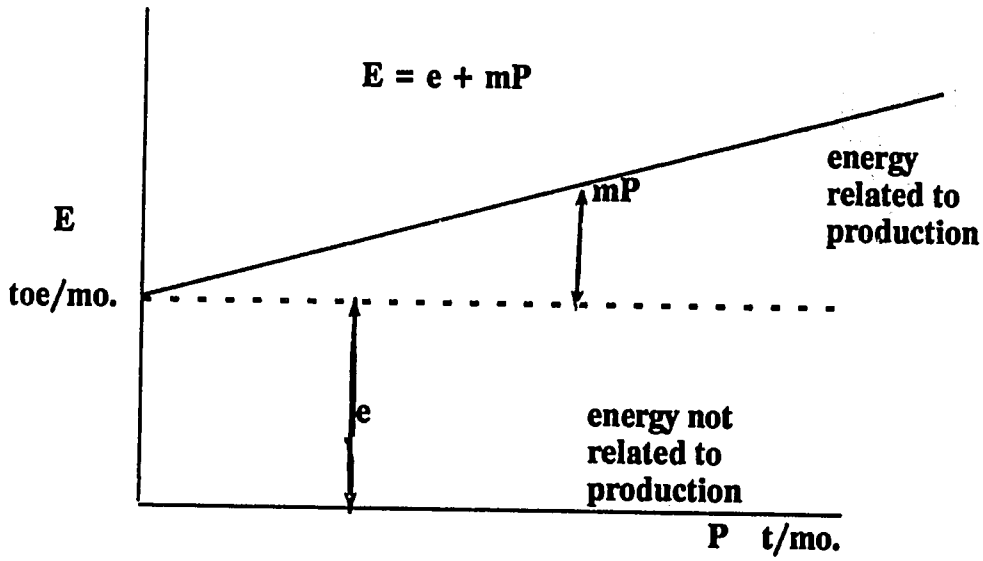

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Exhibit 1.b

Energy Related to Production

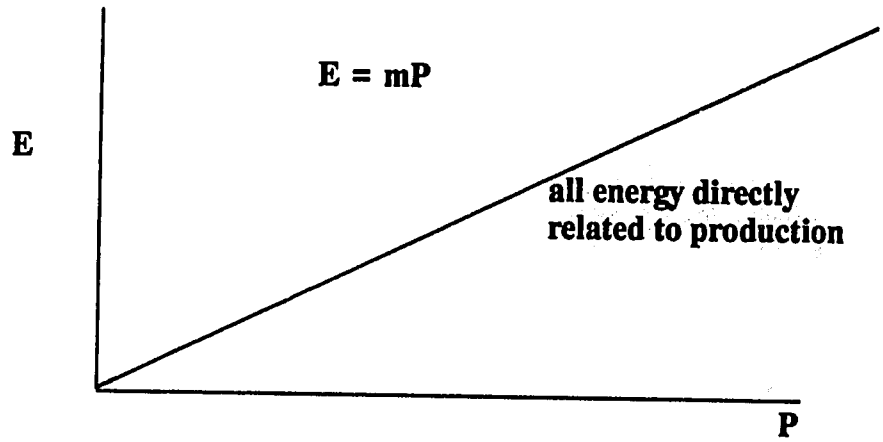


Exhibit 1.c

Independent of Production

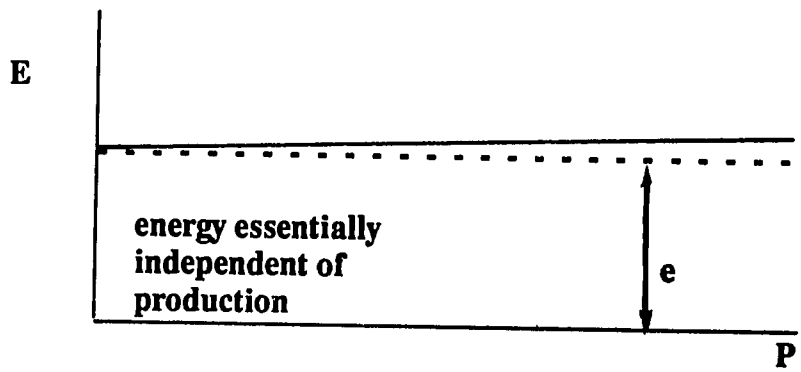
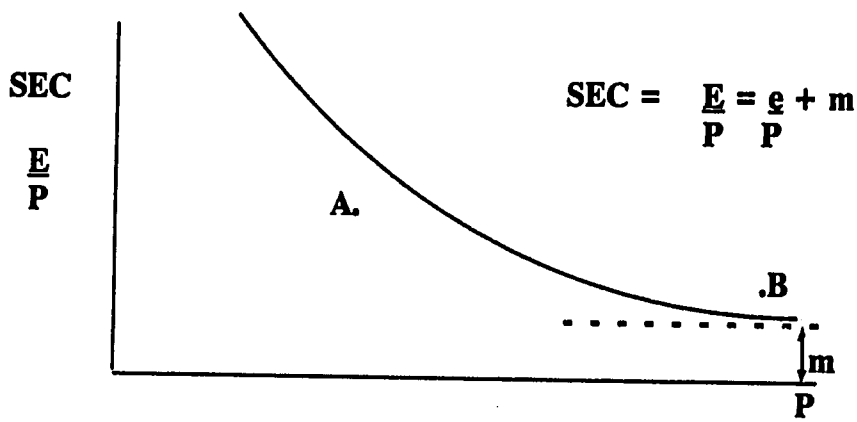


Exhibit 1.d

Specific Energy Consumption



It is therefore extremely important to relate the energy consumption per unit output (SEC) to throughput or capacity utilization. In Exhibit 1.d, for example, point A represents an improvement in energy efficiency compared with typical performance while point B shows a deterioration, even though the actual value of B is lower than A.

1.5.8 Marginal and Average Energy Consumption

The energy standards have been computed on an average basis. This means that a standard is the ratio of the total energy requirement of a process to total output. Multiplying the standard by the total output of a particular product provides an estimate of total energy use for that industrial subsector, assuming good modern practice is adopted in all plants.

Energy standards should not be considered as marginal energy requirements (i.e., the amount of energy needed to produce one more unit of production). Because of fixed energy losses and no-load energy consumption, marginal energy consumption is often much lower than average energy consumption.

CHAPTER 2: ENERGY STANDARDS FOR MAJOR INDUSTRIES

Energy data have been compiled for the following industries:

2.1 Steel
2.2 Cement
2.3 Chemicals
2.4 Food Processing
2.5 Pulp and Paper
2.6 Glass
2.7 Metallurgical Industries
2.8 Miscellaneous Materials of Construction
2.9 Textiles
2.10 Oil Refining

2.1 STEEL

Introduction

The iron and steel industrial subsector is one of the largest consumers of energy in most developed countries, and often represents a significant consumer in developing countries. In general, the subsector includes a wide variety of activities, from quarrying and coke production, through iron and steel production, to rolling, forging and other finishing processes. The range of finished products is diverse (e.g., ingots, billets, slabs, rods, bar, tubes, plates, sheets, coils, castings, forgings).

Worldwide, iron and steel making is undergoing considerable change. In many countries, some of the more energy-intensive processes such as open hearth steelmaking have been eliminated. Continuous casting of hot steel is more widespread, and electric arc steelmaking is being increasingly used to maximize the use of scrap.

Of the steel subsector's many activities, not all are found in every developing country. The main processing routes are illustrated in Exhibit 2.a.

Because of the variety of processing options available, and variations in the source of coke and scrap (both could be imported or domestically produced), care must be taken in interpreting energy consumption data. Factors such as the extent of continuous casting and the availability of high-grade ore are more important in determining energy consumption than differences in the availability of energy-efficient technologies from country to country.

National Data

Specific energy consumption data are presented in Exhibit 2.b for a number of countries. The lowest specific energy consumption figures are recorded for Japan, Italy,

Exhibit 2.a

Simplified Iron and Steel Manufacturing Process Flow Diagram

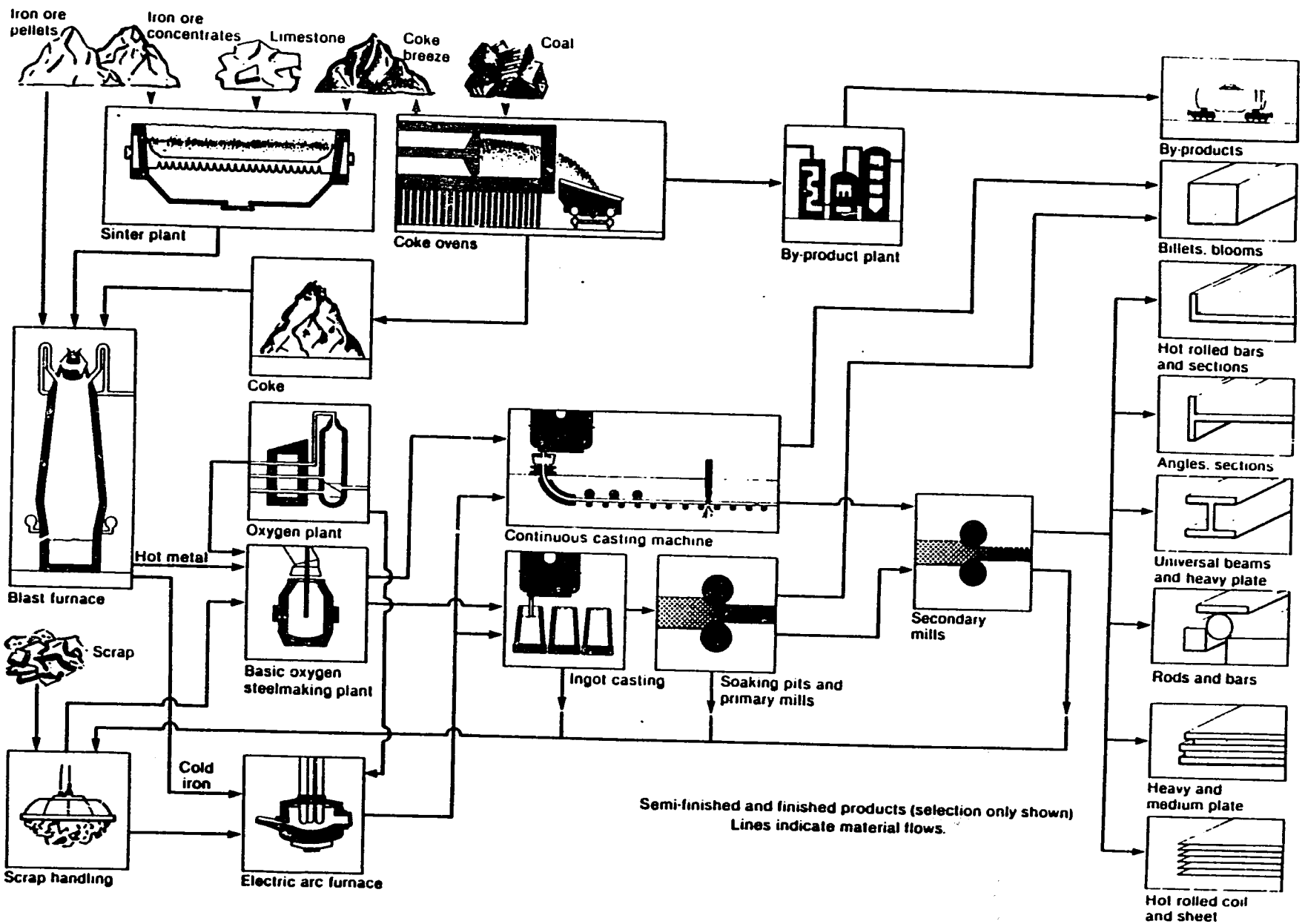


Exhibit 2.b

Energy Used for Steel Processing in Selected Countries

Country	Year	Annual Production (million tonnes)	Specific Energy Consumption (koe/tonne)	Blast Furnace (coke ratio)	% Open Hearth	% Share of Continous Casting
Italy	80	26.5	420	-	-	50
Spain	80	12.7	440	-	-	37
Japan	80	111.4	450	449	0	59
Germany	80	43.8	520	-	7	46
UK(1)	86	-	520	-	-	-
Canada(1)	85	-	550	-	-	-
UK	79	21.5	560	587	0	17
France	80	23.2	570	-	2	41
Brazil	80	15.3	570	480	9	34
USA	80	103.8	620	588	12	20
Yugoslavia	80	3.6	750	706	40	37
Portugal	80	0.6	750	620	-	43
China	80	37.1	910	-	32	7
Columbia	80	0.4	940	740	-	-
Egypt	80	0.8	950	-	-	-
India	80	9.5	980	-	58	0

(1) Source HBC estimate
(2) Source CIPEC 85

All other data from World Bank publications

and Spain; the low energy consumption in Italy and Spain is believed to be the result, at least in part, of relatively high scrap usage.

Process Data

Data for the main steelmaking processes are given in Exhibit 2.c. These data represent good modern practice and may therefore be regarded as reliable standards against which to measure actual performance. Selected figures for blast furnace operations are also given in Exhibit 2.d.

Finishing Operations

Processing of steel downstream of liquid steel production often involves a variety of manufacturing techniques. These may be divided into:

(1) primary finishing: primary rolling or continuous casting for the production of slabs and blooms, often referred to as semi-finished steel

(2) secondary finishing: secondary reheating and rolling for the production of such products as bar, rod, rail, wire, and sheet.

In the ingot casting route, liquid steel cools in the molds until the ingots are safe to handle for removal (i.e, they have a sufficiently solid skin). The time taken to pour all the molds and to cool them, together with metallurgical requirements, will determine the time and fuel required in the soaking pits prior to primary rolling. Mis-scheduling of operations can easily result in inefficiency energy use. Proper control of soaking pits (and reheating furnaces generally) is essential to avoid excessive metal losses in the form of millscale.

In the continuous casting route, most of the losses due to cooling ingots are avoided. The yield of solid metal is also greater than for the traditional ingot casting route. Relatively small amounts of fuel and electricity are consumed by the continuous casting method, and recycling of scrap is minimized (which also has a secondary effect on the energy consumed in the steel mill).

Representative figures for reheating semi-finished slabs or billets, and for rolling to the final plate, sheet or bar, are given in Exhibit 2.e. Losses of metal in secondary processing are normally recycled as scrap to upstream processes (e.g., for remelting in an electric arc furnace).

Exhibit 2.c

Energy and Mass Balance Standards for the Production of Steel

Product-Process	Units	Inputs		Outputs	
Coke plant	t/t coke	Dry coal	1.50	Coke	1.00
				Coke breeze	0.01
				Tars, pitch	0.07
	koe/t coke	Coal	1,036	Coke product	669
		Fuel gas	10	Coke breeze	53
		Steam	16	Excess coke oven gas	122
		Elec. (20 kWh)	7	Tars, pitch	65
				Losses	153
Sinter plant	t/t sinter	Coke breeze	0.060	Sinter	1.00
		Ores	0.996		
	koe/t sinter	Coke breeze	34	Losses	50
		Fuel	4		
		Elec. (22 kWh)	8		
Blast furnace	t/t hot metal	Sinter	1.2	Hot metal	1.00
		Coke	0.50[1]	Slag	0.30
	koe/t hot metal	Coke	332	Misc. losses	100
		Fuels	27	Gas	93
		Elec. (22.2 kWh)	8		
		Steam to Blowers	32		
Basic oxygen steelmaking	t/t crude steel	Hot metal	0.88	Crude steel	1.00
		Scrap or misc.	0.30		
		[oxygen 50 m^3]			
	koe/t crude steel	Elec. (16.7 kWh)	6	Losses	71
		Energy in hot metal	205		
Electric arc furnace	t/t crude steel	Scrap + cast iron	1.12	Crude steel	1.00
	koe/t crude steel	Electricity (570 kWh)	196		
Open hearth furnace	koe/t crude steel	Fuel, steam	115		
		Elec. (17 kWh)	6		

Source

- Energy Audit Report 16: "The Iron and Steel Industry," UK Dept. of Energy and UK Dept. of Industry, 1982.
- Dr. F. Reinitzhuber, "Energy Saving in Iron and Steelmaking," EC Workshop in Nanjing, China, on Energy Saving in Industry, June 1987.

Note

1 Under favorable conditions, consumption of coke and fuels can be under 500 kg per t hot metal.

Exhibit 2.d

International Comparison of Blast Furnace Fuel Charge Rates a/

	Nippon Steel Japan 1980	U.S.A. circa 1973	United Kingdom 1980	Brazil 1979	India circa 1979
Fuel (Gcal/ton of pig iron)					
Coke	3.36	4.30	4.15	3.44	6.12
Fuel oil	0.12	0.14 b/	0.11	0.34	0.00
Natural gas	0.00	0.00	0.00	0.00	0.00
TOTAL	3.48	4.44	4.26	3.78	6.12

Note

a/ Blast furnace fuel charge rates include all fuel that is directly fed or injected into blast furnaces. Energy consumed in the production of steam and hot air blasts is excluded.

b/ An average of 0.09 Gcal of natural gas was also consumed per ton of iron production, but probably mostly for hot-air blast production. Some of the fuel oil may also have been used in hot-air blast production.

Exhibit 2.e

Energy Consumption in Steel Finishing Operations

Product-Process	Units	Inputs		Outputs	
Ingot casting, soaking pit, and primary mill	t/t liquid steel	Liquid steel	1.00	Slabs, blooms	0.87
	koe/t liquid steel to casting	Fuel Elec. (78 kWh) Steam	26 27 1		
Continuous casting	t/t liquid steel	Liquid steel	1.00	Products	0.96
	koe/t liquid steel to casting	Fuel Elec. (15 kWh)	3 5		
Reheating furnace, secondary mill	t/t semi-finished steel	Semi-finished	1.00	Plate or bar product	0.86
	koe/t semi-finished steel	Fuel Elec. (80 kWh)	30 27		

Source: See Appendix A

2.2 CEMENT

Introduction

Cement is manufactured in a large number of developing countries. This subsector includes the quarrying of raw materials, their crushing and grinding, the firing of the materials in a kiln, and the grinding of clinker to prepare the finished product.

The older wet process for cement making still survives in many countries, but the dry process, in its various forms, has become increasingly popular whenever the raw materials prove suitable. Brief descriptions of the processes follow.

Although cement may appear to be simple product, there are many factors that can affect energy use in cement plants. For example:

- The use of slurry thickeners (additives) in the wet process allows the water content of the kiln feed slurry to be reduced while still maintaining pumpability. This means that the fuel used to evaporate water in the kiln can be substantially reduced in some plants.
- Grinding aids for clinker mills can reduce electricity consumption.
- Heat recovery from kilns can be achieved in a variety of ways, e.g., through the use of clinker coolers that preheat combustion air, the use of chains and other kiln internals in hot process kilns and some dry process kilns, the use of multiple stages of feed preheat in dry process kilns.
- The required properties of the finished cement can affect the energy that goes into the manufacturing, e.g. high initial strength cements usually have a high surface area (they are ground to very fine particles) that requires additional electricity in the clinker grinding mills. Care must therefore be taken that the product fineness is comparable when comparing cement plant energy consumption figures.

National Data

Specific energy consumption data are presented in Exhibit 2.f for a number of countries.

Exhibit 2.f

Energy Used for Cement Manufacture in Selected Countries

Country	Year	Annual Production (million)	Specific Energy Consumption			% Wet Process	Cement to Clinker Ratio
			Fuel (koe/t)	Electricity (kWh/t)	Overall (koe/t)		
USA	80	324.0	88.6	142	137.4	52	-
Canada	85	-	-	-	116.5	-	-
Japan	80	-	93.1	102	128.2	-	1.15
Italy	81	43.1	90.0	127	133.7	-	-
India	78	19.5	138.5	123	180.8	65	1.18
Pakistan	80	3.3	151.5	100	185.9	90	1.06
Peru	81	2.4	95.1	145	145.1	13	-
Philippines	79	4.1	122.0	150	173.6	27	1.05
Turkey	78	15.4	103.9	-	-	10	1.04
Tunisia	81	2.2	90.9	120	132.2	21	-

Note: All figures refer to metric tonnes.

Source: Data from the World Bank.

Process Data

There are two main process routes for the manufacture of cement:

(1) Wet process, in which the raw materials are ground in water and then fed to the kiln as a slurry with typically 40-45 percent water content by weight

(2) Dry process, in which the raw materials are prepared without the addition of water and are fed to the kiln as a powder.

The wet process kiln is normally long with steel chains looped near the slurry inlet to effect heat exchange from the hot exhaust gases to the cold incoming slurry. Refractory brick structures (e.g., crosses) are also used in some kilns.

The dry process kiln can also be long with chains or crosses (although excessive dust formation can restrict their use). However, the development of suspension preheater kilns has led to significant improvements in energy efficiency for the dry process. In these kilns, the hot exhaust gases from the kiln are passed through a series of cyclones into which the raw material powder has been introduced in countercurrent to the gases. The intimate mixing of cold feed and hot gases allows good heat transfer.

A more recent development has been the precalciner kiln, which has a supplementary burner outside the kiln in the suspension preheater area. Some calcining of the raw material occurs before it enters the main kiln. The energy efficiency of the precalciner kiln is generally little different from a 4 stage SP kiln, although the throughput of cement for a given sized kiln can be much greater.

Variations on the basic wet and dry process include the semi-wet and semi-dry process, in which some water is added to the raw materials, but not enough to form a slurry. The feed to these kilns is usually in the form of compressed modules (or pellets) that can be fed to the main kiln by a moving grate.

Energy standards for a number of cement plant configurations are shown in Exhibit 2.g. To attain these standards over an extended period, the plant must operate at steady conditions and with a minimum of mechanical breakdowns. This requires a steady feed rate and a stable composition of the raw material mix, so that the plant operating conditions can be set at optimum levels with a minimum of changes.

2.3 CHEMICALS

The chemical subsector covers a broad range of products, from inorganic chemicals made in small quantities to heavy organic chemicals made at the rate of thousands of tons per day. The variety of processes is correspondingly large. Because of the great range of possibilities, national statistics are meaningless for comparison purposes.

Exhibit 2.g

Energy Use in Cement Manufacturing

Electricity (kWh/tonne cement)

Raw material grinding	25	
Clinker grinding	38	
Kiln rotation	20	
Quarry	5	
Miscellaneous, including lighting	12	
	100	**kWh/tonne of cement**
(equivalent to about	34	koe/t)

Fuels

	kCal / kg cement	koe / tonne cement
Wet process (long kiln)	1,200	120
Dry process (long kiln)	820	82
Semi-dry (grate preheaters, lepol type)	800	82
Dry (suspension preheaters)	750	75

Note A typical cement-to-clinker ratio is about 1.10 for standard Portland cement. However, some countries permit the manufacture of "blended cements" in which the clinker is ground and mixed with cementitious materials such as blast furnace slag, naturally occurring pozzolans, or pozzolanic fly ash from power plants firing pulverized coal. The energy consumed for these blended cements per ton of final product will vary considerably from the above figures.

Source Industrial International Data Base, The Cement Industry, Gordian Associates, Inc., for ERDA, 1976 (NATO - CCMS 46).

A list of energy standards for chemicals processing, with indications of the utilities required (cooling water, steam, chilled water, and corresponding electricity and fuel use), is provided in Exhibit 2.h.

Energy consumption figures for different processes in selected countries are shown in Exhibit 2.i.

2.4 FOOD PROCESSING

This industrial subsector covers a broad range of products. Energy use depends on such factors as the quality and characteristics of the raw materials and the specification of the products. Virtually every plant is therefore different, and it is difficult to make international comparisons.

Typical energy consumption in various countries is shown in Exhibit 2.j.

2.5 PULP AND PAPER

In this subsector, many products are manufactured in a variety of mills. Some mills manufacture both pulp and paper products (integrated mills), while others import pulp and convert it to paper. Energy use is affected by the extent of waste paper recycling, and by the use of combined heat and power (CHP) or cogeneration systems. Typical levels of CHP use in Europe are shown in Exhibit 2.k.

Some typical energy standards for well operated mills in different countries are given in Exhibit 2.l. These data were obtained from audits on a number of mills and are the best performances recorded for electricity and fuel figures. However, because wide ranges of fuel and electricity consumption are reported in the literature, these figures must be used as a guide only. Energy standards for selected paper products are given in Exhibit 2.m.

2.6 GLASS

Many different glass products are made by this subsector, including flat glass, various types of containers, domestic or table glassware, and glass fiber products. The basic process steps for almost all glassmaking are:

- Batch preparation
- Melting
- Forming
- Annealing
- Inspection and packing.

Exhibit 2.h

Energy Standards for Chemicals Manufacture (continued)

Product/Process	Raw Material	Unit	Specific Energy Consumption: Fuel (koe/u)	Elec. (koe/u)	Energy (koe/u) 1/	Source	Utilities 2/ 3/: Electricity (kWh/unit)	Cooling Water (M3/t)	(kWh/t)	(t/t)	Steam (koe/t)	(kWh/t)
Acetic acid 4/	Acetaldehyde	t	59.5	59.9	80.1	HP 11/85 P116	6	160	32	0.7	59.5	14
Acetic anhydrid	Acetic acid	t	357.0	281.4	453.8	Halcon	168	147	29	4.2	357.0	84
Ammonia, turbocompressor		t	693.0	48.0	710.3	HP 11/58 p121	48		0		0.0	0
Ammonia, turbocompressor	Natural Gas	t NH3	683.0	133.0	728.8	ICI-AMV	105	140	28		0.0	0
Ammonia, turbocompressor	Naphtha	t NH3	753.0	154.0	806.0	ICI	125	145	29		0.0	0
Ammonia, turbocompressor	Oil	t NH3	848.0	246.0	932.6	Kellogg	200	230	46		0.0	0
Ammonia, turbocompressor	Coal	t NH3	1,130.0	184.0	1,193.3	Kellogg	136	240	48		0.0	0
Ammonia, reciproc compre.	Natural Gas	t NH3	930.0	543.0	1,116.8		512	155	31		0.0	0
Ammonia, reciproc compre.	Electrolyse	t NH3	0.0	10,026.0	3,448.9		10,000	130	26		0.0	0
Sulfuric acid 23/	Sulphur	t H2SO4	-51.00	-173.2	-110.6		-176	74	15	-0.6	-51.0	-12
Phosphoric acid (54% P2O5)		t P2O5	93.5	119.0	134.4		86	55	11	1.1	93.5	22
NPK fertilizers 24/		t NPK	20.2	49.8	37.3		47	0	0	0.1	11.9	3
Calciumcarbide		t	391.0	3,000.0	1,423.0		3,000	0	0		0.0	0
Oxygen		1000 NM	47.6	1,410.2	532.7	Air Liquide, France	1,395	20	4	0.6	47.6	11
Chlorine, mercury cells		t	204.0	3,636.0	1,454.8	HBC	3,573	75	15	2.4	204.0	48
Chlorine, diaphragm cells		t	204.0	2,872.8	1,192.2	HBC	2,811	69	14	2.4	204.0	48
Chlorine, membrane cells		t	75.7	2,846.2	1,054.7	Asahi-Akzo Netherlands	2,798	152	30	0.9	75.7	18
Chlorine, membrane cells 34/		t	127.5	2,839.6	1,104.3	Asahi Chemicals/Fluor	2,779	153	31	1.5	127.5	30
Liquefied chlorine		t	0.0	78.0	26.8	HBC	78	0	0		0.0	0
Acrylonitrile 25/		t	17.0	311.8	124.3	Sohio/Nitto	234	369	74	0.2	17.0	4
ABS resin		t	170.0	687.6	406.5		637	53	11	2.0	170.0	40
Acetone		t	423.3	132.6	468.9	Exxon	22	153	31	4.0	340.0	30
Acetylene 26/		t	2,617.1	48.2	2,633.7	BASF	141	66	13	-5.3	-450.5	-106
Ascorbic acid (vitamin C)		t	1,870.0	6,176.0	3,994.5	Ajinomoto	5,247	2,445	489	22.0	1,870.0	440
Aspartame (sugar replacement)		t	4,250.0	8,174.2	7,061.9	Stamicarbon	6,702	2,361	472	50.0	4,250.0	1,000
Caprolactam		t	1,125.1	1,016.0	1,474.6	Ashland-Continental Carb.	419	1,685	337	13.0	1,105.0	260
Carbon black		t	1,982.9	524.6	1,563.4	Dupont	556	13	3	-1.7	-144.5	-34
EPDM rubber		t	178.5	1,059.4	542.9		959	292	58	2.1	178.5	42
Ethylene 31/ 27/	Gasoil	t	3,733.9	142.2	3,782.8		62	401	80			
Ethylene 32/ 27/	Naphta	t	2,837.3	119.0	2,878.2	HBC	53	330	66			
Ethylene 33/ 27/	Ethane	t	1,555.5	89.8	1,586.4	BASF/Stamicarbon	57	169	34	0.0	-4.3	-1
Melamine		t	503.3	1,295.4	948.9		1,250	27	5	2.0	170.0	40
Phenol		t	444.6	449.8	599.3		306	209	42	5.1	433.5	102
Ethanol 5/		t	357.3	175.0	417.5	HP 11/85 p120	100	25	5	3.5	297.5	70
Ethanol (gasohol grade)	Corn starch	t	423.2	679.4	656.9		589	72	14	3.8	323.0	76
Ethanol	Ethylene	t	370.4	146.2	420.7	VEBA	57	76	15	3.7	314.5	74
Methanol ICI LP 6/		t	780.0	105.6	816.3	HP 11/85 p144	88	88	18		0.0	0
Methanol ICI LP 7/		t	770.0	47.8	786.4	HP 11/85 p144	35	64	12		0.0	0
Methanol ICI LP 8/		t	730.0	49.0	746.9	HP 11/85 p144	35	70	14		0.0	0
Methanol LURGI LP 8/		t	710.5	0.0	710.5	HP 11/85 p145	0		0		0.0	0
Methanol LURGI LP 9/		t	916.3	0.0	916.3	HP 11/85 p145	0		0		0.0	0
Methanol LURGI LP 6/		t	976.1	0.0	976.1	HP 11/85 p145	0		0		0.0	0
Methanol MITSUB LP 8/		t	690.0	12.0	694.1	HP 11/85 p146	0	60	12		0.0	0
Nitric acid SABAR 10/		t	0.0	371.0	127.6	HP 11/85 p150	335	180	36		0.0	0
Linear low density polyethylene 39/		t powder	16.3	763.2	278.8	Union Carbide/Fluor	728	157	31	0.2	16.3	4
Polyethylene HD/MD/LD 11/			8.5	167.9	66.3	HP 11/85 p160	165	5	1	0.1	8.5	2
Polyethylene HD 12/		t pelle	42.5	473.2	205.3	HP 11/85 p161	430	165	33	0.5	42.5	10.0
Polyethylene HD, CX slurry 40/		t	57.5	1,038.9	414.8	Mitsui Petrochemicals/Fluor	945	402	80	0.7	57.8	13.5
Polyethylene UHD		t	75.7	499.2	247.4	Dow	463	92	18	0.9	76.7	17.8

Exhibit 2.h

Energy Standards for Chemicals Manufacture (continued)

Product/Process	Raw Material	Unit	Specific Energy Consumption: Fuel (koe/u)	Elec. (koe/u)	Energy (koe/u) 1/	Source	Utilities 2/ 3/: Electricity (kWh/unit)	Cooling Water (M3/t)	(kWh/t)	(t/t)	Steam (koe/t)	(kWh/t)
Polypropylene SPHERIPOL 13/		t	25.5	14.0	75.0	HP 11/85 p162	120	90	18	0.3	25.5	6.0
Polypropylene bulk process 37/		t	48.9	759.3	310.1	El paso polyolefin/Fluor	705	214	43	0.0	42.3	11.5
Styrene		t	337.4	166.0	394.5	Monsanto/Shell	93	85	17	2.8	238.0	56.0
Styrene 36/		t	230.1	167.1	287.6	Mobil/Badger/Fluor	126	156	31	0.5	42.5	9.9
Polystyrene 14/		t	20.0	136.0	66.8	HP 11/85 p163	120	80	16		0.0	0.0
Vinylchloride monomer (MVC)		t	272.2	172.8	331.6	Goodrich/Mitsui	86	234	47	2.0	170.0	40.0
Vinylchloride monomer (MVC) 35/		t	118.5	109.6	156.2	Mitsui Toatsu Chemicals/Fluor	70	178	36	0.2	17.0	4.0
Polyvinylchloride 15/		t	29.8	179.0	91.4	HP 11/85 p164	160	60	12	0.4	29.8	7.0
Polyvinylchloride 38/		t	38.0	193.9	104.7	Chloe Chimie/Fluor	157	143	29	0.4	37.5	8.7
SBR rubber		t	680.0	773.0	945.9		604	45	9	8.0	680.0	160.0
Urea		t	49.0	39.0	62.4		15	63	13	0.6	49.3	11.5
Urea 16/		t	64.6	52.2	82.6	HP 11/85 p172	21	80	16	0.8	64.6	15.2
Ammonum nitrate CARNIT 17/		t 100%	-10.8	2.9	-9.8	HP 5/85 p113	2	18	4	-0.1	-11.1	-2.5
Pthalic anhydride LAR 22/		t	-366.4	-86.2	-396.1	HP 11/84 p84			0	-4.3	-366.4	-86.2
Dimethylterephtalate 18/		t	277.5	461.6	436.6	Dynamit Nobel	417	73	15	1.5	127.5	30.0
Polyethylene terephtalate 19/		t	249.1	195.8	316.5		163	54	11	1.1	93.5	22.0
Polytetrafluoroethylene		t	84.2	513.0	260.7	Dupont	472	106	21	1.0	84.2	19.8
Silicone Fluids 20/		t	164.3	395.0	287.8		276	225	45	1.9	161.5	38.0
Sodiumcarboxymethylcellulose		t	2,550.0	2,995.6	3,580.5	Hoescht	2,147	1,243	249	30.0	2,550.0	600.0
Sodiumchlorate		t	81.6	5,927.0	2,120.5		5,840	339	68	1.0	81.6	19.2
Titanium dioxide (chloride process)		t	1,286.7	896.4	1,595.1	Tioxyde	573	417	83	12.0	1,020.0	240.0
Titaniumoxyde 21/		t	1,286.7	896.4	1,595.1		573	417	83	12.0	1,020.0	240.0
Toluene diisocianate		t	349.1	477.4	513.3		432	202	40	0.3	213.0	5.0
MTBE		t	208.5	110.1	246.4		38	163	33	2.0	170.0	40.0
Linear alkylbenzene PACOL 23/		t	180.4	256.8	268.7	HP 11/84 p87	248	20	4	0.2	20.4	4.8

Source: (where not specified) RCG/Hagler, Bailly derived from energy audits and numerous technical publications.

Exhibit 2.h

Energy Standards for Chemicals Manufacture (continued)

Notes

1/ Based on 25% generation and distribution efficiency (0.344 koe/kWh)
2/ Utilities based on the following figures:

Utility	Unit	Fuel (koe)	Electricity (kWh)	Source
Cooling water	M3	0.00	0.20	HBC
Steam	Tonne	85.00	20.00	HBC

3/ Steam figure for utilities is the average primary energy use for a boiler plant without cogenerstion include such auxiliaries as air fans, feed pumps, make-up pumps air compressors, small other auxiliaries but exclude cooling water system (pumps and towers).
4/ Acetaldehyde: 764 kg/t; oxygen: 205 NM3/t
5/ From ethylene; yield: 97%
6/ Ex heavy residue
7/ Ex naphta
8/ Ex natural gas
9/ Ex Coal
10/ Ex ammonia (281 kg/t) and air
11/ Gas phase process; Ziegler catalyst; ethylen: 1,020 kg/t
12/ Slurry phase: ethylene: 1,015 kg/t; hydrogen .6 kg/t; diluent 9 kg/t
13/ Spherical form polymer, excluding granulation (+150 kWh/t)
14/ Styrene: .98 kg/t; mineral oil: .03 kg/t
15/ VCM: 1,007 kg/t
16/ Ammonia: 570 kg/t; carbon dioxyde: 740 kg/t; including liquid effluent treatment
17/ 99.7% wt solution; HNO3 60 wt%: 1,312.4 kg/t100%AN; NH3 100 wt%: 212.8 kg/t100%AN
18/ Without waste treatment
19/ Fiber grade
20/ From alkylchlorosilanes
21/ Solfate process; based on limenite ore
22/ Orthoxylene: 925 kg/t
23/ From sulfur with credit for steam
24/ Average figure including specific energy value for ammonia
25/ Including specific energy value for propylene and ammoina
26/ Partial oxydation of natural gas
28/ With titanium anode and electrodes distance control, including salt extraction (50 kWh/t) and caustic soda concentration, 0.8863 t Cl2/t NaOH
Including auxiliaries = 180 kWh/t
29/ Including auxiliaries = 100 kWh/t
30/ Including auxiliaries = 90 kWh/t
34/ Caustic soda 50%: 1.09 t NaOH/t Cl2; hydrogen: 29.8 kg H2 / t Cl2; salt: 1.69 t salt/t Cl2
35/ Ethylene: .464 t/t VCM; chlorine: .572 t/tVCM; oxygen: .145 t/tVCM
36/ Benzene: .816 t/tstyrene; ethylene: .307 t/tstyrene; production associee de toluene: 63.7 kg/tstyrene
37/ Synthesis + finishing; propylene: 1.029 t/t; ethylene: 15 kg/t; hydrogen: .3 kg/t
38/ Synthesis + finishing; VCM: 1.007 t/t
39/ Synthesis + finishing; ethylene: .935 t/tPE; butene: 90 kg/tPE; hydrogen: .5 kg/tPe
40/ Synthesis + finishing; ethylene: 1.012 t/tPE; butene 1: 7.77 kg/t; hydrogene: .457 kgt

Exhibit 2.i

Energy Used for Chemicals Manufacture in Selected Countries

Product	Country	Year	Annual Production Unit	Annual Production Quantity	Specific Consumption Fuel (koe/unit)	Specific Consumption Elec. (kWh/unit)	Specific Consumption Total (koe/unit)	Source
Caustic soda + Cl2	Sri Lanka	83	t NaOH		558.0	3,061.0	1,610.0	Parathan Chemicals Corporation
Caustic soda + Cl2	Morocco	86	t NaOH			2,940.0	1,011.4	Societe Nationale d'Electrolyse
Caustic soda + Cl2	Turkey	84	t NaOH			3,200.0	1,100.8	
Ammonia	Egypt	86	t		1,220.0	1,350.0	1,654.4	Mercury cells (Seka-Izmit)
Ammonia 1/	Zimbabwe	85	t NH3			37,930.0	1,304.9	Abu Zaabal Fertizer & Chemicals Co.
Ammonia 2/	Yugoslavia		t NH3		816.5	1,713.3	1,405.9	
Ammonia 3/	Yugoslavia		t NH3		1,232.2	146.1	1,282.5	
Ammonia 4/	Yugoslavia		t NH3		929.4	754.0	1,185.7	
Urea	Yugoslavia	84	t	535,000	27.6	28.4	36.8	World Bank
Urea	Pakistan		t		102.0	182.4	164.7	
Calcium ammonium nitro	Yugoslavia	84	t	992,000	0.0	1,546.0	531.8	
Sulfuric acid 6/	Turkey	84	t	332,800	7.0	12.0	11.1	World Bank
Ammonium sulfate	Turkey	84	t	200,000	52.7	87.7	82.9	World Bank
MP 20/20	Turkey	84	t	111,175	60.1	153.0	112.7	
Phosphate fert. 8/	Tunisia	87	t P205		15.7	-1.2	16.1	SEAPA
Tires	Italy	81	t		523.8	1,451.0	1,022.9	Ceat
Tires 7/	Morocco	87	t		321.0	950.0	647.8	Good-Year Maroc 87

Note

1/ Electrolysis
2/ Texaco Process 1962
3/ Chemico 1970
4/ Foster Wheeler 1968
6/ Long term target is 422 koe/t for total energy use (Carnot Law)
7/ After energy conservation and including sulfuric acid units; phosphoric acid 54%
8/ Sulfur: 466 kep/t P205; PCI sulfur: 390 kep/t sulfur

Source: RCG/Hagler, Bailly, Inc.

Exhibit 2.j

Energy Used for Food Processing

Product	Country	Year	Specific Consumption Fuel (koe/tonne)	Elec. (kWh/unit)	Total (koe/unit)	Source
Cane Sugar 1/	Peru	81	282.9	0.0	282.9	IEA
Cane Sugar 2/	Peru	82	535.1	132.0	580.4	
Fruit canning	Egypt	86	19.0	100.0	53.4	Edfina Co. for Canned Food
Oil & soap	Egypt	86	20.6	n/a	20.6	Cairo Co. for Oils and Soap
Edible oil	Sri Lanka	83	29.1	70.9	53.5	British CeyLan Corp.
Soap	Zimbabwe		450.0	118.0	490.6	
Beer	Haiti	84	10.0 7/	100.0 7/	53.4	Brasserie Nationale
Beer	Zimbabwe		1.0 7/	9.5 7/	4.3	
Beer,brewery	Senegal	84	4.8 7/	15.2 7/	10.0	SOBOA
Beer, bottling	Senegal	84	1.4 7/	2.6 7/	2.3	SOBOA
Sausage/meat	Austria	81	93.2	400.0	230.8	Weiser, Vienna
Cookies/wafers/choc.	Austria	81	148.8	1089.0	523.4	Manner, Vienna
Cookies	France	83	120.5	n/a	120.5	General Biscuit
Veg. canning & frozen	Austria	81	70.3	87.0	100.2	Felix
Veg. canning 5/	France	85	68.0	72.0	92.8	Vernet, Energie plus 12.85 p48
Flour milling	Senegal	82	0.0	96.7	24.0	Grands Moulins de Dakar
Tea	Sri Lanka	82	0.2		0.2	
Milk concent. 3/	France	85	15.6 6/	2.7 6/	16.6	UNL. Energie plus 10/85 p36
Milk concent. 4/	France	85	0.8 6/	14.4 6/	5.7	UNL. Energie plus 10/85 p36

Note

1/ Sugar/cane = 9.67%; bagasse/cane = 35.3%; bagasse low heat value + 1.50 toe/t; steam production = 2.55 t/t bagasse
2/ Including the use of bagasse (waste fuel)
3/ Concentration using steam
4/ Steam + MVR concentration
5/ With heat pump
6/ Consumption per tonne water removed
7/ Consumption per hectoliter

Source: RCG/Hagler, Bailly, Inc.

Exhibit 2.k

Pulp and Paper Industry

Percentage of Total Power Requirements Supplied by CHP (Combined Heat and Power) in European Countries

	1980
United Kingdom	37.8
West Germany	61.0
Italy	46.2
France	37.1
Netherlands	Negligible
Belgium	22.9
Denmark	23.9

Source: Paper Industry National Federations.

Exhibit 2.1

Energy Used for Pulp and Paper Manufacture in Selected Countries

Country	Year	Unit	(FAO) Annual Production Pulp	Paper	(Purchased Energy) Specific Energy Consumption Fuel (koe/t)	Electr. (kWh/t)	Total (koe/t)	Source
Canada	81	Mt	19.28	13.84			340	OECD
U.S.A.	81	Mt	47.20	57.67			350	OECD
Brazil	81	Mt	2.95	3.10			330	World Bank
India	81	Mt	0.51	1.06			1,720	World Bank
Japan	81	Mt	8.60	16.98	279.00	699.00	380	OECD
Korea	81	Mt	0.21	1.78	240.00	737.00	454	KME
Turkey	81	Mt	0.28	0.51			990	World Bank
Finland	81	Mt	7.34	6.14			550	OECD
France	81	Mt	1.77	5.15			360	OECD

Exhibit 2.m

Energy Standards for Selected Products in the Pulp and Paper Industry

	Fuel (koe/ton)	Electricity (kWh/ton)	Total (koe/ton)
Pulp (sulfate)	401	709	645
Pulp (sulfite)	110	245	194
Writing papers	337	175	397
Packaging papers	248	342	366
Tissue	389	960	719
Board	193	200	262

Source: Audit Report 3 (EUR 8792) "Pulp, Paper and Board Industry in the European Economic Community."

Variations are possible at each stage, however, so the energy used to manufacture different products can vary considerably.

Batch preparation includes the receipt, weighing, and mixing of raw materials, and the delivery of the mixed batch to the furnace. The raw materials are mainly sand, limestone, and soda ash for containers, and the same materials plus dolomite for flat glass. Some additives are often included, usually amounting to only 1-2 percent of the total. For crystalware, the main raw materials are sand, red lead, potash, and potassium nitrate. The energy used depends on the condition of the raw materials as received by the plant. For example, many plants import sand that is too wet to process immediately and must be dried using a rotary drier (fired by fossil fuel).

Many glass plants use recycled broken glass (cullet) as part of the batch to the melting furnace. This cullet reduces the energy requirement for glass manufacture by a significant amount. For a typical plant, the use of 10 percent cullet will reduce the energy required for melting by up to 4 percent.

A large proportion of the energy consumed in glass manufacture is used in batch melting. The working temperature of the melting furnace is about 1500°C, and large quantities of energy leave the furnace as hot combustion gases. Most glass-melting furnaces are equipped with extensive heat recovery systems, the most common being recuperators used to preheat combustion air. The amount of fuel needed to fire the furnace will depend on the efficiency of the recuperator system, which itself depends on the design and nature of the recuperator packing and on optimizing the cycle time. Some glass melting furnaces have additional waste heat boilers for steam raising after the recuperator sections. Energy consumption can vary greatly from one plant to another, depending on plant configuration.

Although most melting is done using fossil fuels, some glass works use electric melting, especially for small batches of specialty glass. Large furnaces may also use electric boosting to increase the throughput of existing fuel-fired systems. Provided the electric heaters are positioned to promote convection currents within the molten glass, electric boosting can be very effective.

Finally, since heat losses from the glass furnace can be substantial, the insulation of the walls and roof is important for energy efficiency. When a furnace is nearing the end of its useful life and requires a comprehensive rebuild, insulation can easily break down, resulting in local energy losses (often severe).

Energy standards for various products in the glass processing subsector are shown in Exhibit 2.n.

Exhibit 2.n

Energy Standards for Glass Manufacture

Product/Process	Unit	Specific Energy Consumption Fuel (koe/u)	Electr. (kWh/u)	Total (koe/u)
Glass container 4/	t containers	180	373	308.3
Batch handling	t melt. glass		52	17.9
Melting 5/	t melt. glass	160		160.0
Melting 6/	t melt. glass	110		110.0
Forming	t melt. glass		255	87.7
Annealing (NG)	t melt. glass	1		0.5
Annealing (elec)	t melt. glass		5	1.8
Tempering	t containers		275	94.6
Product handling	t containers		66	22.7
Flat glass 7/	t flat glass	153	543	339.8
Flat glass 8/	t flat glass	312	543	498.8
Batch handling	t melt. glass	34	9	36.9
Melting (NG)	t melt. glass	170		170.0
Melting (NG)	t melt. glass	150		150.0
Forming	t melt. glass		200	68.8
Annealing	t melt. glass	3		3.0
Bending (NG)	t flat glass	142		142.0
Bending (elec)	t flat glass		387	133.1
Tempering	t flat glass		275	23.7
Laminating	t flat glass	17		17.0
Product handling	t flat glass		34	11.7
Textile glass fiber 9/	t fiber glass	40	3,850	1,364.4
Batch handling	t melt. glass		110	37.8
Melting (fuel)	t melt. glass	277		277.0
Melting (elec)	t melt. glass		1,940	667.4
Forming	t melt. glass		1,630	560.7
Drying	t fiber glass	40		40.0
Product handling	t fiber glass		170	58.5
Wool glass fiber 9/	t fiber glass	336	2,840	1,313.0
Batch handling	t melt. glass		170	58.5
Melting	t melt. glass	277		277.0
Forming	t melt. glass		2,500	860.0
Binder ap./curing	t fiber glass	59		59.0
Product handling	t fiber glass		170	58.5
Pressed and blown glass 10/	t finis prod	643	1,800	1,232.2
Batch handling	t melt. glass		10	34.4
Melting	t melt. glass	500		500.0
Forming	t melt. glass		1,500	516.0
Fire polishing	t finish prod	65		65.0
Annealing	t finish prod	78		78.0
Product handling	t finish prod		200	68.8

Note

1/ Converting electricity to primary energy on the basis of 0.344 koe/kWh (25% efficiency)
2/ Converting electricity to primary energy on the basis of 25% efficiency (3,440 kCal/kWh)
4/ Container to melt glass ratio: 80%
5/ Without cullet; theroretical melting energy of batch glass: 120 koe/t. Flat glass to melt glass ratio: 80%
6/ With 80% cullet; theoretical melting energy of cullet: 83 koe/t. Flat glass to melt glass ratio: 80%
7/ Tempered glass
8/ Bended & laminated glass
9/ Fiber glass to melt ratio: 100%
10/ Blown glass to melt glass ratio: 84%

2.7 METALLURGICAL INDUSTRY

This industrial subsector is particularly broad, making international comparisons difficult. Some figures for selected products in a number of countries are given in Exhibit 2.o. The data will be expanded in the next edition of this directory.

2.8 MISCELLANEOUS MATERIALS OF CONSTRUCTION

Materials used for construction range from timber to bricks, tiles, and concrete blocks. Owing to different building standards and different historical methods and materials of construction, energy consumption for the various products can vary considerably from one country to another.

Bricks are a common material for the construction industry in most countries. Brick raw materials, processing methods, and fired product specifications are all highly variable. Specific fuel consumption reported in Europe in 1980 for different kiln types and kiln sizes is shown in Exhibit 2.p.

The impact of raw material characteristics in brickmaking is shown clearly in Exhibit 2.q. For most of the countries listed, the fossil fuel usage ranges from 2.6 GJ/tonne to 4 GJ/tonne, with the exception of the Fletton brick industry in the UK, which reports 0.83 GJ/tonne. This is because the clay used for the bricks has a high carbon content, which contributes to more than 75 percent of the total energy input to the kilns.

The brick subsector in many countries has converted largely to continuous tunnel kilns, which are generally more efficient than other types, as indicated in Exhibit 2.r. The bulk of the energy used in brickmaking is represented by the fuel fired in kilns and ovens (with heat recovery from kilns for drying purposes being an important factor in improving energy efficiency). Nevertheless, electricity is also used to a significant extent, as shown in Exhibit 2.s.

Energy used for other construction materials varies very widely. Examples of energy use in a few countries are shown in Exhibit 2.t.

2.9 TEXTILES

Again, this industrial subsector covers a wide range of activities using many different types of materials, ranging from natural raw materials such as wool and cotton to synthetics and blends of all kinds. Much of the energy consumed in textile plants is used for the drying of cloth after various wet processing operations such as bleaching, dyeing, and washing. Large quantities of hot and cold water are used, the heat coming mostly from steam. The extent of heat recovery in a textile plant is therefore critical to its energy efficiency. Where it is practical to remove water by mechanical means (e.g. by centrifuging) prior to drying, substantial savings can be realized.

Exhibit 2.o

Energy Used for Metallurgical Industries in Selected Countries

Product	Country	Year	Annual Production Unit	Quantity	Energy Use Fuel (koe/tonne)	Elec. (kWh/tonne)	Specific Consumption Fuel (koe/tonne)	Elec. (kWh/tonne)	Total (koe/tonne)	Source
Lead Bars	Peru	81	kt				482.0	180	544	Centromin Peru
Copper cathode	Peru	80	kt				198.0	362	323	Minero Peru (from blister)
Zinc bars	Peru	82	kt				26.0	3849	1,350	Minero Peru
Aluminium	U.S.A.	82	kt	92.2	2,392.1	354.7		17600	6,054	Pacific Northwest Plants
Aluminium	Austria	81	kt					14200	4,885	
Aluminium	India	82	kt				975.0	18500	7,339	
Lead	Morocco	86	kt	55.0			191.4	322	302	Ste des Fonderies de Plomb de Zellidja
Lead	Peru	82	kt	85.3			482.0	180	544	Centromin
Steel melting	Malaysia	85	kt					570	196	Electric arc furnace
Ferrochrome 1/	Zimbabwe	84	kt alloy	150.0	n/a	691.5		4610	1,586	Aimasco
Ferrochrome 2/	Zimbabwe	84	kt	25.8	13.1	212.1	508.0	8220	3,336	Zimalloys
Ferrosiloconchrome	Zimbabwe	84	kt	21.9	12.5	174.1	571.0	7951	3,306	Zimalloys
Ferromanganese	Zimbabwe	84	kt	1.8	n/a	6.4		3533	1,215	Zimalloys

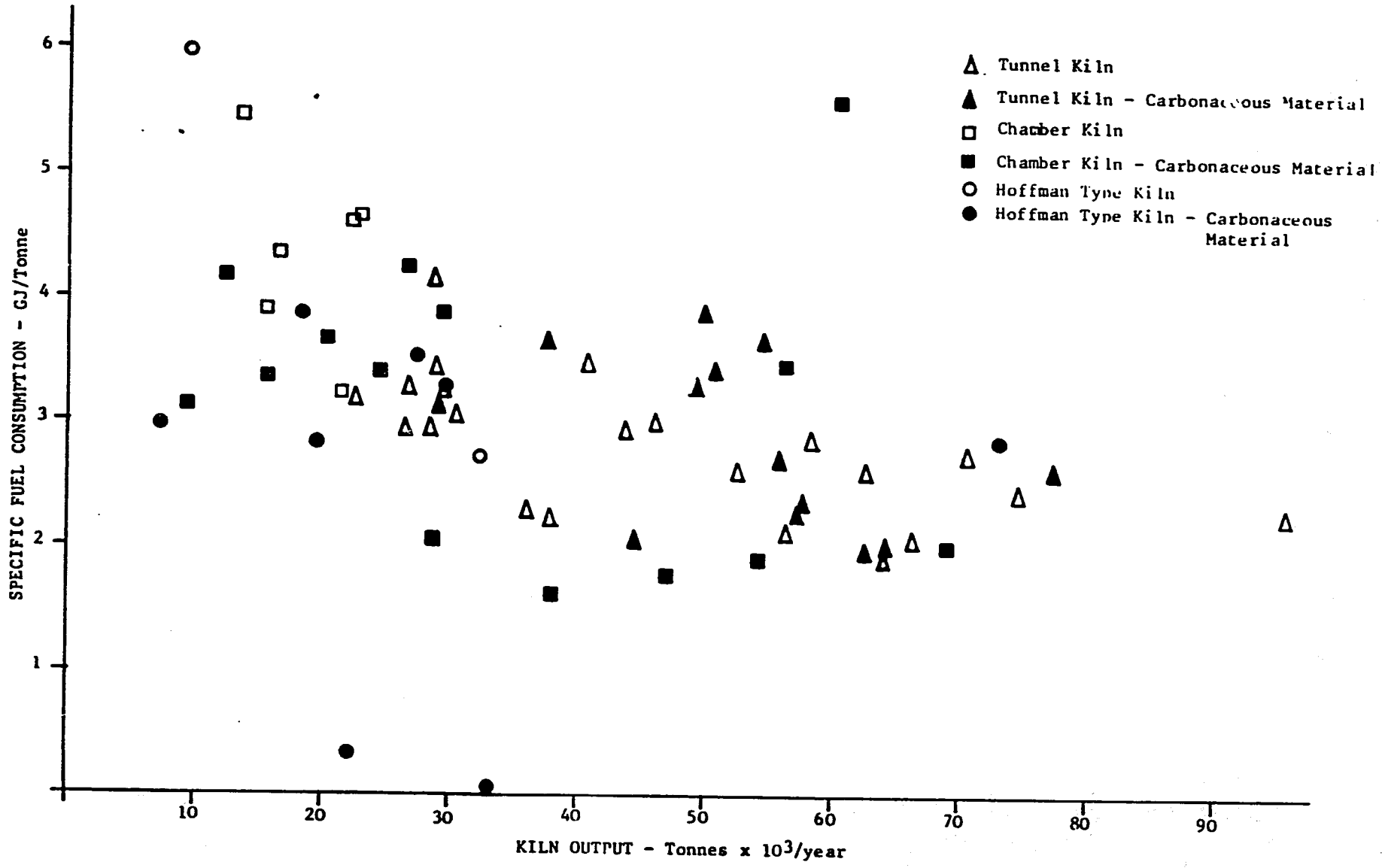
Note

1/ High carbon
2/ Low carbon

Source: RCG/Hagler, Bailly, Inc.

Exhibit 2.p

Fuel Consumption For Drying and Firing in Brick Works



Data for 1980.

Source: Commission of the European Communities, Energy Audit No. 5, "Clay-Brick Industry in the EEC", (EUR 9469), 1985.

Exhibit 2.q

Brick Production and Energy Consumption in Selected Countries

		Belgium	Denmark	Eire	France	Germany	Greece**	Italy	Netherlands	U.K.	
										Fletton	Non-Fletton
Output (Tonnes x 10^6)	Bricks	1.70	0.73	0.05	0.57	5.64	2.03	5.46	4.35	4.13	4.87
	Blocks	1.86	-	-	3.67	9.65	0.87	13.10	-	-	-
	Tiles	-	-	-	2.15	-	-	1.24	-	-	-
TOTAL		3.56	0.73	0.05	6.39	15.29	2.90	19.80	4.35	4.13	4.87
Total fossil fuel (GJ x 10^6)		10.42	1.9	0.20	16.73	42.65	7.58	76.0	14.0	3.45	14.72
Specific Energy (GJ/Tonne)		2.93	2.60	4.0	2.62	2.79	2.61	3.84	3.22	0.83	2.93
Total Electricity (KWh x 10^6)		154.5	41.7	4.0	358.6	751	121	1240	112	85.7	232.3
Specific Electricity (KWh/Tonne)		43.4	57.1	80	56.1	49.1	41.7	62.6	25.7	20.7	46.2
No. of Kilns	Tunnel	95%*	40	2	250	480	54%*	45%*	45	0	62
	Annular	-	2	1	18	20	44%*	55%*	60	68	60
	Intermittent	-	1	-	43	3	2%*	-	5	-	67
	Clamps	6	-	-	-	-	-	-	-	-	23
Brick Production (%)	Wirecut	70	43	100	100	92*	100	100	23	-	77
	Pressed	-	-	-	-	3*	-	-	-	100	11
	Soft-mud + Handmade	30	67	-	-	15*	-	v small	77	-	12

* Estimated % of production

** Approximate values

Source: EEC report EUR 9469, op. cit.

Exhibit 2.r

Specific Fuel Consumption for Different Brick Kilns

GJ/ton

Type of Plant	U.K.	Ireland	Denmark	France	Italy	Germany	Netherlands	Overall Range
Tunnel Kiln	2.3-3.7	2.2-2.5	2.3-3.8	1.5-2.5	2.7	1.5-4.0	2-3	1.5-4.0
Chamber	2.2-4.6	2.5-2.7			3.1		1.5-4.5	2.2-4.6
Intermittent	4.8-6.3			3.3-5.9			5-8	3.3-8.0

Source: EEC report EUR 9469, op. cit.

Exhibit 2.s

Typical Specific Electricity Consumption in the Brick Industry

(kWh/ton) Bricks	Plant A	Plant B
Type of Brick	Extruded	Soft mud
Type of Dryer	Chamber	Tunnel
Type of Kiln	Tunnel	Annular
Winning	1.3	3.3
Preparation	8.6	12.7
Making	7.9	4.9
Drying	11.9	7.6
Firing	10.6	11.0
TOTAL	**40.7**	**39.5**

Source: EEC report EUR 9469, op. cit.

Exhibit 2.t

Energy Used for Construction Material Processing in Selected Countries

Product	Country	Year	Specific Consumption Fuel (koe/unit)	Elec. (kWh/unit)	Total (koe/unit)	Source
Refractories	Egypt	86	310.0	126.0	353	Arab Ceramic Co.
Tiles (small)	Malaysia	86	280.0	435.0	430	
Floortiles	Malaysia	86	60.0	387.0		
Sawn timber	New Zealand	82	0.0	419.0 1/		UNIDO
Bricks	Canada	85			227	CIPEC 85 2/
Refractories	Canada	85			156	CIPEC 85

Note

1/ Consumption is expressed by koe and kWh per M3
2/ Consumption is expressed as koe per thousand standard brick

Source: RCG/Hagler, Bailly, Inc.

Some energy standards for typical textile products are shown in Exhibit 2.u. Examples of energy used for textiles processing in several countries are given in Exhibit 2.v.

2.10 OIL REFINING

Oil refineries typically consist of one or more crude oil distillation units, followed by various downstream processing units to convert intermediate streams into finished products. For example, a catalytic reformer converts straight run naphtha into high octane gasoline blending components. The energy consumption of an oil refinery is thus the total of the consumption of each individual unit, which depends on throughput, mode of operation, the type of crude oil feedstock, and the desired specifications of the products. Each refinery is a different entity whose energy efficiency is specific to the situation in the refinery at any time.

Standard figures for the process yields and energy consumption of typical refinery units are given in Exhibit 2.w. Yields from process units can be altered significantly by changing operating temperatures and pressures, so the data in the exhibit are typical figures only and can vary for any specific refinery.

The fuel required to operate a crude distillation unit depends to some extent on the degree of heat integration used in the plant design. Assuming good, modern practice in the use of heat exchangers, the fuel required will depend on the crude oil characteristics. Light crudes require more fuel than heavy crude because of the heat of vaporization of the light fraction, which is a higher proportion of the crude. A guide to the fuel required as a function of crude oil gravity is shown as Exhibit 2.x.

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Exhibit 2.u

Energy Standards for Textile Processing

Product/Process	Unit	Specific Energy Consumption: Fuel (koe/u)	Electr. (kWh/u)	Energy (koe/u)	Source
Yarn formation 4/	t	0.0	2,457.9	845.5	Energetics
Carding 10/	t	0.0	185.7	63.9	Energetics
Drawing	t	0.0	54.6	18.8	Energetics
Roving	t	0.0	109.2	37.6	Energetics
Spinning 11/	t	0.0	1,649.5	567.4	Energetics
HVAC	t	0.0	458.8	157.8	Energetics
Texturizing 12/	t	0.0	2,555.1	879.0	Energetics
Fabric formation 5/	t	22.2	1,428.8	513.7	Energetics
Winding	t	0.0	100.5	34.6	Energetics
Slashing	t	22.2	174.8	82.3	Energetics
Weaving 13/	t	0.0	705.7	242.8	Energetics
HVAC	t	0.0	447.9	154.1	Energetics
Combed yarn spinning 18/	t	0.0	3,429.0	1,179.5	Energetics
Knitting 6/	t	0.0	860.8	296.1	Energetics
Knitting	t	0.0	773.4	266.0	Energetics
HVAC	t	0.0	87.4	30.1	Energetics
Fiber bonding	t	0.0	439.1	151.1	Energetics
Floor covering (Dry) 7/	t	44.4	840.0	333.4	Energetics
Twisting	t	0.0	410.7	141.3	Energetics
Heat setting	t	44.4	158.7	108.3	Energetics
Tufting	t	0.0	134.4	46.2	Energetics
HVAC	t	0.0	109.2	37.6	Energetics
Yarn dyeing and drying	t	361.1	0.0	361.1	Energetics
Woven fabric dye & finish 8/	t	815.0	380.2	945.8	Energetics
Heat setting	t	11.1	10.9	14.8	Energetics
Singeing	t	5.6	0.0	5.6	Energetics
Preparation	t	100.0	43.7	115.0	Energetics
Mercerization	t	42.8	93.9	75.1	Energetics
Dyeing 14/	t	166.7	109.2	204.3	Energetics
Printing 15/	t	252.8	108.2	290.0	Energetics
Finishing 16/	t	86.7	0.0	86.7	Energetics
Drying 17/	t	149.4	13.1	153.9	Energetics
Knit fabric dye & finish 9/	t	503.6	32.8	514.9	Energetics
Preparation	t	75.0	32.8	86.3	Energetics
Dyeing	t	213.3	0.0	213.3	Energetics
Finishing	t	104.2	0.0	104.2	Energetics
Drying	t	111.0	0.0	111.1	Energetics
Floor covering (wet)	t	643.9	0.0	643.9	Energetics
Dyeing	t	416.7	0.0	416.7	Energetics
Finishing	t	100.0	0.0	100.0	Energetics
Drying	t	127.2	0.0	127.2	Energetics
Drying cylinders	t	154.0	0.0	154.0	Werner

Note

1/ Converting electricity to primary energy on the basis of .344 koe/kWh (Carnot Law)
2/ Convering electricity to primary energy on the basos of 10.45 MJ/kWh (Carnot Law)
4/ Including carding, drawing, spinning, HVAC
5/ Including winding, slashing, weaving, HVAC
6/ Including knitting and HVAC
6/ Needleless knitting systems
7/ Including twisting, heat setting, tufting, HVAC
10/ Direct feed carding system
11/ Open head spinning; 18.5 yarn count
12/ Air-jet technology
13/ Shuttleless looms
14/ Foam dyeing
15/ Foam printing
16/ Form finishing
17/ Mechanical predrying + heat recovery on dryer exhaust
18/ 35 yarn count

Source: RCG/Hagler, Bailly, Inc.

Exhibit 2.v

Energy Used for Textile Processing in Selected Countries

Product	Country	Year	Annual Production Unit	Annual Production Quantity	Energy Use Fuel (ktoe)	Energy Use Elec. (GWh)	Specific Consumption Fuel (koe/t)	Specific Consumption Elec. (kWh/t)	Source
Cotton print cloth	Niger	84	t	4,400.0			940	6,500	Sonitextile
Textile industry	Colombia	81					1,490	4,700	Lima seminar
Textile industry	USA	84	kt	4,906.0	4,980.0	25,115.00	1,015	5,119	Energetics
Spin to finish	Colombia	81	t	22,980.0	56.8	150.30	2,400	6,500	IEA
Spinning	Columbia	81	t	984.0	0.0	4.38	--	4,400	IEA
Spin & weav	Columbia	81					--	12,500	IEA
Spin to finish	Sri Lanka	84	t	1,058.0			2,200	6,500	Pugoda Textile Mills
Finish. shirt.	Portugal	81					847	1,171	Somelos
Cotton finishing	Senegal	82					1,270		ICOTAF
Velvet	Italy	81					1,400	950	Bellora
Printing	Italy	81					207	588	Zucchi
Weaving	Italy	81					163	1,163	Zucchi

Source: RCG/Hagler, Bailly, Inc.

Exhibit 2.w

Energy and Yield Standards for Oil Refining Processes

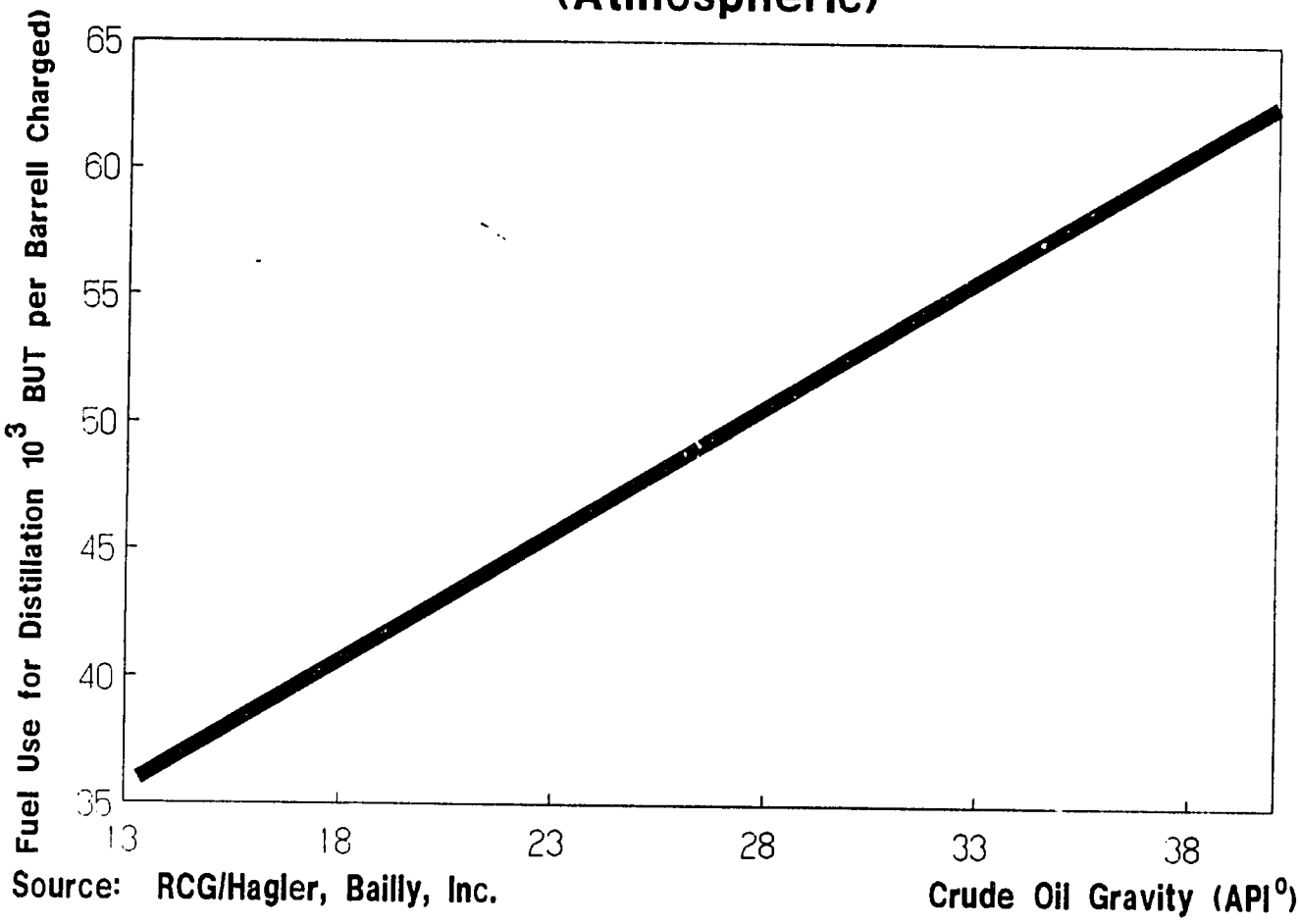
Yields 1/	Crude Distillation						CAT Cracker 3/ 4/		CAT Reformer 5/ 6/		Delayed Coker	HVF Alkylation	Naptha HDT	Distillate HDT
	Arabian Heavy	Arabian Light	Murban	Kirkuk	Es Sider	Soviet Blend	Low Severity	High Severity	Low Severity	High Severity				
Crude Oil Density (API)	28.0	33.0	39.0	34.9	36.5	34.5								
Fuel gas	.001	.003	.006	.004	.006	.003	.020	.028						
C3	.001	.005	.008	.005	.015	.008	.012	.020	.015	.017				
C4	.005	.008	.008	.016	.017	.017	.035	.048	.255	.332				
Gasoline	.030	.042	.043	.046	.044	.053	.174	.238 7/						
Naphtha	.075	.116	.123	.136	.118	.122								
Kerosene	.040	.026	.029	.036	.027	.037								
Gasoil	.348	.338	.352	.331	.358	.325	.104	.070						
Reduced Crude 2/	.500	.462	.350	.426	.415	.435								
Fuel Oil Component														
Coke							.616	.581						
Hydrogen Rich Gas							.101	.015						
Reformate									.010	.012				
									.720	.639				
Utilities														
Fuel (toe/t)	0.012	(average)					0.025	0.030	.065	.080	0.045	.085	.016	.015
Steam 9/	0.030	"					.4 8/	.5 8/	.17 /8	.17 /8	.03	0.2 10/	0	0
Elec (kWh/t)	7	"					35	35	20	20	12	40 10/	7	10

Note

1/ Yields are expressed in tonnes per tonne of feedstock, assuming no losses.
2/ Vacuum distillation of reduced crude will yield around 50% distillate, 50% short residues, depending on the crude oil type and the desired cut point.
3/ Catalytic cracker yields can be changed greatly by changing the catalyst and operating conditions.
4/ Low severity is equivalent to 25% wt. conversion (gasoline and lighter); high severity, 35 % wt. conversion.
5/ Yields are highly dependent on the catalyst type and operating parameters.
6/ Severity is measured by reformate octane number (clear, unleaded); low severity=88 ON, high=94 ON.
7/ Cat. cracker gasoline octane nos.: low severity=88, high severity=94.
8/ Net steam production assuming waste heat recovery.
9/ Expressed as tonnes of steam per tonne charge to the process unit. For 70% efficiency of steam generation, these figures may be multiplied by 0.076 to give an estimate of tonnes fuel oil equivalent per tonne of charge.
10/ Utilities per tonne of product alkylate

Source: RCG/Hagler, Bailly, Inc.

Exhibit 2.x
Fuel Required for Crude Oil Distillation (Atmospheric)



Source: RCG/Hagler, Bailly, Inc.

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