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ENERGY IN DEVELOPING COUNTRIES SERIES

Industrial Energy Demand and Conservation in Developing Countries

John E. Jankowski, Jr.

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The views expressed in this paper are, however, those of the author and should not be interpreted as representing the views of either A.I.D. or Resources for the Future.

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INTRODUCTORY NOTE

The countries of the developing world are important to the evolving energy future. Their contribution to the demand for world oil and other energy sources is at present small, but its rate of growth is high. Indeed, as development continues the nations of the Third World may provide most of the growth in oil use for the rest of this century.

Because of the importance of developing countries to global energy outcomes, and of energy outcomes to the prospects for development, we have undertaken a series of studies designed to illuminate the dynamics of demand changes and the opportunities for (and barriers against) supply enhancement. One major portion of this effort is funded by the Agency for International Development under the ARDEN (A.I.D.-RFF Development and Energy) Cooperative Agreement No. AID/DSAN-CA-0179.

The ARDEN program is divided into three main subprogram areas: 1) rural electrification, 2) biomass, and 3) energy demand and conservation, within which this discussion paper falls. "Industrial Energy Demand and Conservation in Developing Countries" is an in-house analytic study designed to review, synthesize and analyze existing work in the topic area and to identify specific issues with a view to future work in collaboration with overseas institutions in developing areas.

Although similar studies have been made for several developed countries, (see RFF's How Industrial Societies Use Energy, for example), to our knowledge this is the first systematic effort to compare industrial energy use among developing countries, both sector wide and by

specific manufacturing subsector. This study challenges the popular supposition that similarity in technology makes industrial energy use for comparable outputs near-uniform across countries. The wide range of energy intensities found in like industries suggests that the industrial sector may offer substantial opportunities for energy conservation.

The results from the exploratory study reported on here have led us to initiate several studies of industrial energy use. An examination of industrial energy conservation in Ecuador is already under way in an effort to remedy some of the data deficiencies noted. Carried out by the Instituto Nacional de Energia in that country, 550 industrial enterprises (covering 90 percent of the industrial production) are being surveyed in order to find out how much energy they consume (in total and by fuel), for which purposes, and with what resulting output. Through pioneer efforts such as this, a data base can start to accumulate from which robust inferences can be drawn.

Work of a somewhat different nature but addressed to the same issues has also begun in India under the direction of Dr. R. K. Pachauri, at the Administrative Staff College of India (Hyderabad). The Indian work contemplates a full-scale analysis of the effect of increases in energy prices on the amount of energy consumed in industry, and on consequent shifts in the amounts of other factors of production consumed.

"Industrial Energy Demand and Conservation in Developing Countries" introduces a topic which we believe deserves widespread attention and further research. We issue this report on work in progress with the multiple purposes of informing the policy community of the state of knowledge, of stimulating research elsewhere and of eliciting comments on our own efforts.

Milton Russell
Director, Center for
Energy Policy Research

Chapter 1

AN ARGUMENT FOR INDUSTRIAL ENERGY CONSERVATION IN DEVELOPING COUNTRIES

Picture thousands of industrial machines grinding to a halt throughout the developing world, victims of insufficient energy supplies. Energy for growth gives way to energy for survival, supplies being either unavailable or obtainable only at prohibitive prices. Industrial growth, planned in an age of energy plenty, comes to a standstill, as do the aspirations for a better future--the once promised result of the industrializing economy.

Although this worst-case scenario is most unlikely, the second oil shock of 1979-80 once again brought into question the complacency regarding the availability and cost of energy for the world in general and for the developing countries in particular. Massive foreign credit, both private and official, allowed many developing countries to absorb with relative ease the effects of the 1973-74 oil price quadrupling and subsequent world recession.[1] In the five years following the first oil price jump both petroleum and total energy consumption grew in the developing countries at an annual 6.5 percent pace. That was down substantially from the 8.5 percent rate of the preceding decade, but was a far smaller decline than in the industrialized nations where a 1963-73 growth rate of 7.5 percent fell to a rate of less than one-half percent in the 1973-78 period. The prospects of continued growth in the LDCs are not as likely this time around. Since most developing countries do not possess significant re-

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[1]For a discussion of this adjustment process see Brittain and Cleveland (1977) and Dunkerley (1980).

serves of the commercial fuels, a rapidly mounting energy import bill brought on by ever-increasing energy needs looms ahead. The problem's potential severity is illustrated by the World Bank's estimate of the future oil production/consumption gap in net oil importing countries, which is expected to widen from 4.5 million barrels a day oil equivalent (MBDOE) in 1980 to 7.8 MBDOE in 1990--a 70 percent increase (!) (World Bank, 1980a, p. 49). Combine this expanding import dependence with rising prices and the severity of this problem is compounded.

In an increasingly tight world energy situation it is precisely these developing countries, whose current account deficit is already over $40 billion, who will be in the least competitive position for acquiring the scarce supplies. Consequently, the question is what may be done in these oil importing LDCs to avoid what may seem the inevitable--economic stagnation brought on at least in part by energy scarcity.

Structure of the Report

Our format is to move from the aggregate to the specific. The remainder of this chapter briefly reviews the historical perception of conservation and provides rough estimates of industrial energy conservation potential. Chapter 2 details general trends and cross-country comparisons of aggregate industrial energy usage. Both industrialized and developing countries' records are discussed. This process shows that there are occasionally large variations in industrial energy demand among countries which, as documented in How Industrial Societies Use Energy (Darmstadter, et al., 1977) is the result of two interrelated factors--structure of the sector and intensity of energy use. Both structural and intensity characteristics are themselves manifestations of a variety of factors--geography, resources endowment, product mix, technology, demographic factors and economic policies. Chapter 3 looks at such structural characteristics in several developing countries, while chapter 4 compares cross-country energy intensities in various manufacturing industries. Chapter 5 summarizes and presents several closing observations.

The Need for Conservation

As in any economic equation the energy question has both demand and supply implications. In order to moderate the political and economic costs

of insufficient energy supply or of energy dependence on foreign supply sources a country has three courses of action. It may devote its efforts toward securing and/or augmenting energy supplies--that is, supply expansion. It may concentrate instead on extending those which are already available by reducing energy requirements--that is conservation, which is part of the demand variable. Or it may simply attempt to substitute its problem energy supplies with less costly ones; less costly in the political and/or economic sense; for example, diversification of oil import supplies from OPEC to non-OPEC producers. Most likely a country will pursue a combination of the three courses. The purpose of each is essentially the same. Indeed, in some respects, energy conservation and supply expansion can be viewed as part of the same resource base. The implementation of conservation measures, which reduces energy demand, has the effect of extending energy supplies.

Any energy assessment must take into consideration both cost and time of development. It may be cheaper and/or quicker to save a unit of energy than to provide an additional one. This time factor for developing new and/or less conventional energy supplies or new methods of energy production often requires ten to fifteen years, regardless of the financial effort. On the other hand, much energy-using capital stock (cars, household appliances, industrial machinery) turns over quicker than this. Evidence indicates that significant amounts of energy may be "acquired" in less than five years resulting from demand shifts for energy.

Up until 1973, energy policies in most countries--where there were any--were generally ad hoc and oriented toward individual fuel supply. Countries might have a coal policy and an electricity policy, but they were often in the domain of different government agencies and there was little recognition of the implications of policy for one fuel on the development of another. Policy actions themselves were often just reactions to particular problems as they arose. And energy demand, if not ignored, was given heed only through taxation measures for fiscal reasons or subsidization of, for example, rural electricity and kerosene for social reasons, neither policy directly related to energy demand management.

Even after the 1973 price rise the record shows that energy policy throughout the world remained supply dominated although there has been more attention to the potential of interfuel substitution, primarily for

oil. There have been few policy initiatives on the demand side, especially with regard to pricing policy. A 1979 International Energy Agency assessment of conservation efforts in the industrialized countries notes that:

> the value of energy conservation continues to be underestimated....Strong private and public institutional structures to promote conservation, similar to those that exist for energy development, have not been established and many conservation programmes are still based disproportionately on information and voluntary actions. Without sufficient incentives and supporting pricing policies, the effectiveness of these programmes may be substantially reduced...(IEA, 1979, p. 19).

For many years the term "conservation" had derisive connotations throughout the world. There was an accepted link between increasing energy consumption and growing national output which was itself associated with the improvement of a nation's power and status, both economic and political, as well as with alleviating potentially explosive domestic, social and economic conditions. Energy was relatively inexpensive and supplies abundant and, for countries whose development plans emphasized rapid expansion of the industrial base, growing energy consumption was a natural corollary. Conserving resources was seen, at a minimum, as foolish--how can one conserve something whose absolute level of consumption is so low?--or, more likely, retrogressive.

The twelve-fold increase in oil prices between 1973-81 has changed this perspective. The oil-importing countries have found it increasingly necessary to export ever larger amounts of real output to pay for their energy needs. In doing so they have experienced a real decline in economic welfare. As a consequence, conservation is no longer viewed as simply doing without resources or doing with much less which in turn entails the deprivation of conveniences or even necessities. Rather, it is seen as a means of forestalling the rate at which welfare declines from previously expected growth levels. There is a greater appreciation that there are conservation measures by which energy consumption can be made more efficient. It is also better understood that conservation efforts can help alleviate short-term fuel shortage and, augmented by new sources of energy, long-term problems of supply and demand. Such measures can serve to save scarce foreign exchange, as well as resolve balance-of-payments difficulties. It is increasingly recognized that it might indeed be pos-

sible to decrease energy use without necessarily reducing real living standards through substitution among labor, capital and energy inputs. However, it must also be emphasized that if conservation is pushed beyond cost-effective levels, there will be a decline in economic efficiency.

An understanding of energy conservation potential is provided by the laws of thermodynamics.[2] According to the first law, all energy is conserved, that is, not lost. However, the efficiency of energy conversion and usage (useful work delivered) in any given task is such that:

$$\text{Efficiency (I)} = \frac{\text{energy transfer achieved by a device or system}}{\text{energy inputs to a device or system from some source (i.e., total energy consumed)}}$$

Notice that to accomplish an energy-based task there are two requirements: an energy source and an energy-converting device. Efficiency (I) therefore measures the efficiency of the device. The problem with Efficiency (I) is that it ignores the question of whether the particular source and/or device are the right ones in the first place or whether another may be more technically appropriate for the task. These questions are better accommodated by the second law of thermodynamics. The second law recognizes that while energy cannot literally be lost, it can be dispersed so that it cannot be used further to perform work. Thus, not only the quantity of energy input, but also the quality, must be taken into account to fully assess energy efficiency in physical terms, the so-called second law efficiency:

$$\text{Efficiency (II)} = \frac{\text{absolute minimum energy required for a given task}}{\text{energy inputs to a device or system from some source (i.e. total energy consumed)}}$$

Note that this is a <u>task</u> minimum, not a <u>device</u> maximum which therefore suggests two rules for energy efficiency in this second law sense: (1) Do not use a higher quality energy source than the task deserves and (2) for a given source choose the device which generates the most useful work or heat. Consequently, for every task there is some combination of energy-converting device (accompanied by its ideal functioning) and energy source (subject to its availability) which should be utilized for maximum energy efficiency.

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[2] For a more detailed discussion see American Institute of Physics (1975), and Reddy and Prasad (1977).

Given the rudimentary understanding of conservation in the thermodynamic sense, it is then necessary to apply economic criteria to the goal of reducing energy demand. It is not sufficient simply trying to approach the maximums of second-law efficiency or even improving the ratio of the first law. Options which provide the greatest level of energy conservation may not be economically best. There is a point where the marginal cost of saving a unit of energy will be larger than the marginal benefit associated with such savings. To determine this equilibrium one must consider the total cost of production and use of energy including the fuel mix, availability of supply and substitution possibilities; preferably at the factory level. Except occasionally, and for expositive purposes, this paper explores the actual physical demand for energy in the developing countries, rather than analyzes this question of microeconomic optimization.

The Industrial Sector

While energy conservation potential exists in all sectors of the economy, we review only the energy trends and conservation opportunities offered by industry. Table 1-1 presents aggregate energy consumption apportioned between sectors for six developing countries. Based on these data there appears to be great variability of sectoral energy usage among countries.[3] When commercial and traditional (for example, bagasse and fuelwood) fuels are included, energy consumption in the household/commercial sector (which also includes energy consumption in agriculture and public service sectors) dominates. The transportation and industrial sectors follow, each covering a wide range of percentage contributions to total energy demand. If, however, traditional fuels are excluded, the household/commercial sector falls to third or fourth place in terms of sectoral importance since a large amount of energy consumption in this sector is met by traditional fuels. Rather, as is indicated by this sample, industry and transportation consume most commercial fuels in many developing countries. In fact, over the last decade or so industrial pro-

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[3] It is noted at the outset that care must be used not to attribute too much exactness to these aggregate data. They are estimates at best. However, the data do provide enough precision to be illustrative of general trends and concepts.

Table 1-1. Percentage Distribution of 1976 Energy Consumption in Six Developing Countries[a]

Commercial and traditional fuels	
Household/Commercial	13-79 percent
Industry	6-44 percent
Transportation	4-33 percent
Transformation losses	4-28 percent
Non-energy uses	1-4 percent
Commercial fuels	
Industry	19-45 percent
Transportation	18-40 percent
Transformation losses	16-27 percent
Household/commercial	10-20 percent
Non-energy uses	1-8 percent

Source: International Energy Agency, Workshop on Energy Data of Developing Countries (Paris, Organisation for Economic Co-operation and Development, 1979).

[a]Brazil, India, Kenya, Mexico, Nigeria and Thailand.

duction and industrial energy demand have been growing faster than output and energy consumption in other sectors of their economies. In addition, industry is a major end user of imported oil and unlike, for example, in the transportation sector there are many instances where interfuel substitution possibilities exist.

The potential for successful industrial energy conservation in the developing countries is indicated by the efforts taking place in the industrialized countries. For example, the voluntary "targets" program initiated in the United States for ten manufacturing industries which consume over 90 percent of manufacturer's total purchased energy show large energy savings are possible. Between January 1973 and 1980 the goal was to improve energy efficiencies by an average of 17 percent, 1.2 million barrels

of oil per day (see table 1-2). By 1978, six of the ten had already reached their conservation targets and conservation measures were still far from exhausted (Office of Industrial Programs, 1979, p. 5). This increase in industrial energy efficiency came primarily from easy-to-implement "housekeeping" measures which have low or negligible costs.[4] Other contributing factors include increased capacity utilization and capital investment in energy conserving technologies. The success of these voluntary efforts in the United States serve to indicate their potential in the manufacturing industries of developing countries. Additionally, since many third world countries are still in the beginning stages of major industrialization programs, the opportunities to utilize energy-efficient technology should be even greater in LDCs than in the developed nations, which already have well-established industrial bases. Estimates vary, but in the United States industrial energy-saving potential is quite large over the next twenty-five years--25-40 percent--which should provide a minimum target for the developing countries. In fact, one study has estimated potential industrial petroleum savings in the developing countries at up to 90 percent over the next five to twenty-five years (see table 1-3). This study provides a background for accpeting or rejecting such estimates.

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[4]The determinant factor as to what constitutes "housekeeping" measures is cost. Housekeeping changes require only low to negligible costs and are generally easy to implement. The savings from such measures are usually felt within a year. Examples include economy in use of air conditioning and lighting, production scheduling for minimizing energy consumption, avoidance of idle running of machines, small investments to lower leakage, improved plant maintenance, installation of insulation, and utilization of appropriate energy monitoring and measurement control programs.

Table 1-2. 1972 Industrial Consumption and 1980 Energy Conservation Targets for the United States

	1972 Consumption (10^{12} Btu)	1980 Energy efficiency improvement targets (%)	
		Net	Gross
Primary metals	4,246	9	14
Chemicals	3,087	14	17
Petroleum and coal products	2,993	12	20
Stone, clay and glass	1,462	16	16
Paper products	1,388	20	23
Food products	1,047	12	13
Textiles	474	22	25
Fabricated metals	442	24	25
Machinery	437	15	17
Transportation equipment	414	16	18
Ten industries	15,990	13	17

Source: Office of Industrial Programs, U.S. Department of Energy, Industrial Energy Efficiency Program Annual Report July 1977 Through December 1978 (Washington, D.C., U.S. Department of Energy, December 1979) pp. 2 and 36.

Table 1-3. Industry Energy Savings in the United States and the Developing Countries as Percentage of Total Industrial Energy Demand (percent)

	Immediate (0-1 Years) operational and house-keeping changes	Near term (2-5 Years) small investments in retro-fitting and process changes	Long term (5-25 Years) major technology or system changes
United States			
Total energy	5-10	10-15	10-15
Electricity	5-10	5-10	5-10
Developing Countries			
Petroleum	5-10	5-15	20-90

Source: Electric Power Research Institute, Efficient Electricity Use, Second Edition (New York, Pergamon Press, Inc., 1978) p. 7; Philip Palmedo and Pamela Baldwin, The Contribution of Renewable Resources and Energy Conservation as Alternatives to Imported Oil in Developing Countries (Port Jefferson, New York, Energy/Development International 1980) pp. 57-58.

Chapter 2

INDUSTRIAL ENERGY TRENDS AND CROSS-COUNTRY COMPARISONS

As indicated in chapter 1 and detailed in table 2-1, energy consumption by industry in the developing countries has been growing at a pace equal to or exceeding total energy consumption.[1] This means that the share of industrial energy consumption in the total has been rising, reflecting the generally increasing share of the industrial sector in their Gross National Product. Although the data are very fragmentary, there is little to suggest that LDC industrial energy consumption fell after the 1973/74 oil price rise as much as it did in the industrialized countries. Indeed, in two of the seven developing countries listed in table 2-1--India and Portugal--the rate of industrial energy consumption actually accelerated after the price increases. Only in Brazil did the price rise appear to affect industrial energy demand much more so than other sectors of the economy.

Contrariwise, in each of the four developed countries listed, the rates of industrial energy consumption declined significantly, and in both Germany and the United States such consumption was also absolutely lower in 1976 than it had been in 1973. By 1978 industrial energy consumption in these two countries had still barely reached 1973 levels.

Aggregate growth rates, however, do not tell the story of conservation efforts, but rather end results. Variations or reductions in industrial energy consumption may derive from three very separate develop-

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[1] For a discussion of the methodology utilized in deriving energy consumption along with the problems encountered, see Appendices A and B.

Table 2-1. Total Energy Requirements and Industrial Energy Consumption[a]
(million metric tons oil equivalent)

	1967	1973	1976	Growth rates Average annual percent 1967-73	1973-76
Brazil					
T.E.R.[b]	54.3	89.6	107.2	8.7	6.1
I.E.C.[c]	11.0	26.1	25.9	15.5	-0.0
India					
T.E.R.	87.7	111.7	129.0	4.1	4.9
I.E.C.	24.2	36.3	43.3	6.2	7.5
Kenya					
T.E.R.	3.5	4.6	4.5	4.6	-0.4
I.E.C.	.1	.4	.5	19.8	8.5
Mexico					
T.E.R.	40.8	60.2	73.1	6.7	6.7
I.E.C.	16.7	26.5	33.2	8.0	7.8
Portugal					
T.E.R.	4.9	7.6	8.6	7.6	4.0
I.E.C.	1.4	2.4	3.2	9.1	9.5
Thailand					
T.E.R.	4.0	9.6	11.1	15.7	5.0
I.E.C.	.9	2.9	3.2	21.5	10.4
Turkey					
T.E.R.	N.A.	24.5	29.4	N.A.	6.3
I.E.C.	2.9	5.5	6.7	10.8	7.1
United States					
T.E.R.	1,336.8	1,744.1	1,766.7	4.5	0.4
I.E.C.	428.5	544.6	521.6	4.1	-1.4
Germany					
T.E.R.	186.7	265.8	263.7	6.1	-0.3
I.E.C.	71.9	104.4	96.1	6.4	-2.7
Italy					
T.E.R.	88.7	132.6	136.2	6.9	0.9
I.E.C.	34.1	62.6	63.3	10.1	0.4
Japan					
T.E.R.	194.6	337.8	344.4	9.6	0.[illegible]
I.E.C.	88.1	158.9	169.2	10.3	2.1

Note: Percentage growth rates based on more detailed data than shown above (see Appendix A).

N.A. = Not available.

Source: International Energy Agency, Workshop on Energy Data of Developing Countries, vol. II (Paris, OECD, 1979); International Energy Agency, Energy Balances of OECD Countries (Paris, OECD) (various issues).

[a]Includes energy sector and noncommercial fuels.

[b]T.E.R.: Total energy requirements includes primary and secondary energy sources.

[c]I.E.C.: Industrial energy consumption.

ments: absolute output changes, structural changes or energy intensity changes. For example, a country may experience a 10 percent decline in industrial energy consumption from some base period, which might seem to indicate a substantial energy conservation effort. However, the cause of this energy decline may be that the country experienced a 10 percent absolute decline in industrial output. The industry product mix and factor intensitites remain relatively the same, but with the reduced output, there are reduced energy requirements. In reality the energy fall accompanying a 10 percent output decline would probably be less than 10 percent. This is because the reduction in output would most likely entail capacity underutilization which, because of indivisibilities in energy-using equipment, such as boilers, results in higher energy coefficients per unit of output.

Second, the energy decline in this hypothetical country may have resulted from changes in the product or industry mix of the whole sector, which reduces the contribution of highly energy-intensive industries, such as iron and steel, in favor of less energy-intensive industries, such as metal fabricating. The absolute industrial output remains unchanged, but the structure of the industrial sector is transformed, reducing energy requirements by 10 percent.

Finally, it is possible that conservation occurred in the sense that the intensity of the production process changed. For example, due to process innovations 10 percent less energy could be used to manufacture a ton of steel or a ton of paper than had previously been the case. More technically, and to be addressed more completely in chapter 4, the "specific energy consumption" for a unit of output has fallen.

Industrial Growth

Table 2-2 addresses the question of absolute changes in industrial production and the relationship to changes in energy consumption. By dividing a country's index of industrial energy consumption by its industrial production index, which measures absolute growth changes in its industrial output, it is possible to outline the general relation between absolute changes in output and absolute changes in accompanying energy requirements. Except occasionally, for single years, industrial output was growing in all countries over the 1967-77 period. Only in the de-

Table 2-2. Indices of Industrial Production,[a] Industrial Energy Consumption[b] and Their Relative Changes
(1970 = 100)

	1967	1973	1974	1976	1977
Brazil					
Industrial Production	71	147	159	184	189
Ind. Energy Consumption	78	185	180	184	N.A.
IEC/IP[c]	109	126	113	100	N.A.
Colombia					
Industrial Production	82	127	133	136	N.A.
Ind. Energy Consumption	N.A.	120	145	150	131
IEC/IP	N.A.	94	109	111	N.A.
India					
Industrial Production	83	112	114	131	138
Ind. Energy Consumption	74	111	120	133	N.A.
IEC/IP	89	99	106	101	N.A.
Kenya					
Industrial Production	77	130	142	161	N.A.
Ind. Energy Consumption	39	114	142	146	160
IEC/IP	50	89	100	91	N.A.
Korea					
Industrial Production	57	176	225	357	407
Ind. Energy Consumption	59	106	127	184	226
IEC/IP	104	60	57	52	55
Mexico					
Industrial Production	78	124	133	142	147
Ind. Energy Consumption	83	132	144	165	211
IEC/IP	107	107	108	116	143
Portugal					
Industrial Production	74	136	139	138	155
Ind. Energy Consumption	77	129	158	170	176
IEC/IP	104	95	114	123	114
Turkey					
Industrial Production	88	135	144	172	N.A.
Ind. Energy Consumption	87	160	166	197	207
IEC/IP	99	119	115	114	N.A.
United States					
Industrial Production	94	120	120	120	129
Ind. Energy Consumption	88	112	112	107	108
IEC/IP	94	93	93	89	84
Germany					
Industrial Production	76	113	111	114	116
Ind. Energy Consumption	82	119	127	109	103
IEC/IP	108	105	115	96	89
Italy					
Industrial Production	85	114	120	122	123
Ind. Energy Consumption	72	133	137	135	133
IEC/IP	85	117	114	110	108
Japan					
Industrial Production	66	127	122	122	127
Ind. Energy Consumption	70	126	134	134	132
IEC/IP	106	99	110	110	104

Table 2-2 (continued)

Note: N.A. = Not available.

Source: United Nations, Statistical Yearbook (New York, UN) (various issues); International Energy Agency, Workshop on Energy Data in Developing Countries (Paris, OECD, 1979), and Energy Balances of OECD Countries (Paris, OECD) (various issues).

[a]Industrial production index includes mining, manufacturing and utilities, but not construction. For Kenya, index is for manufacturing only.

[b]Includes energy consumption in the energy sector, excluding transformation losses, and includes both commercial and noncommercial fuels.

[c]Index of industrial energy consumption divided by the index of industrial production where the base is 1970 and the resulting index ratio for 1970 = 100.

The ratios measure the change of energy consumption per unit of industrial production relative to the consumption/output relationship in 1970.

veloped countries has industrial output tended to stabilize; in the eight developing countries it continued to expand rapidly even after the 1973-74 price rise and 1974-75 world recession. Given the industrialized countries' record for slowly rising output, coupled with their slowed and even negative rates of industrial energy growth detailed in table 2-1, we find their Industrial Energy Consumption/Industrial Production ratios declining since the post-embargo period. This is not to say that other factors did not play a role in energy conservation efforts, but only that slowing industrial production helps explain some of the slowing in the rate of industrial energy consumption since 1973.

The record in the developing countries since 1973 is not as clear. In three of the countries listed--Colombia, Mexico and Portugal--energy consumption per unit of industrial output appears to have been rising, but in others it was either stable or falling. Although the issues will be addressed more closely in the following chapters, it suffices to note that individual country trends may be the product of two offsetting developments. The first is the growing importance of heavy industry with its large energy requirements per unit of industrial output, and the second is the effect of the introduction of energy-saving technology. This second factor may be of particular importance in Korea where rapid rates of growth have probably led to a relatively energy-efficient stock of indus-

Table 2-3. Industrial Energy Consumption/Industrial Output Ratios
(metric tons oil equivalent per $ million 1977 output by industry)

	IEC[a]/IO[b] (includes energy sector)			IEC[c]/IO[d] (excludes energy sector)			Useful IEC[e]/IO[d] (excludes energy sector)		
	1967	1973	1976	1967	1973	1976	1967	1973	1976
Brazil	804	1,008	612	814	841	648	601	638	505
India	2,367	2,866	2,568	2,564	3,091	2,871	1,819	2,233	2,095
Kenya	391	766	844	92	591	733	53	457	573
Mexico	1,319	1,432	1,516	1,491	1,527	1,453	1,209	1,247	1,062
Portugal	396	414	567	365	406	481	293	305	399
Thailand	566	1,011	903	544	965	974	407	752	744
Turkey	717	660	711	638	495	615	499	401	498
United States	940	1,072	956	881	945	895	730	790	740
Germany	681	642	756	368	407	382	287	331	313
Japan	431	478	416	631	558	672	507	453	547

Source: United Nations, Statistical Yearbook (New York, UN) (various issues); World Bank data services (Washington, D.C.); International Energy Agency, Workshop on Energy Data of Developing Countries (Paris, OECD, 1979) and Energy Balances of OECD Countries (Paris, OECD) (various issues); W. D. Nordhous, editor. Proceedings of the Workshop on Energy Demand, International Institute for Applied Systems Analysis (Laxenburg, Austria, IIASA, 1975) p. 527.

[a] Includes energy consumption in the energy sector, excluding transformation losses, and includes both commercial and noncommercial fuels.

[b] Industrial output derived from UN breakdown of GDP by economic activity related to World Bank GNP data in 1977 dollars.

Table 2-3 (continued)

[c]Excludes energy consumption in the energy sector.

[d]Industrial output from the manufacturing sector only.

[e]Adjusts for the varying thermal efficiencies of fuels in the non-energy industrial sector. See appendix A for specific adjustment factors.

trial equipment. Contrariwise, in Mexico rising industrial output is more than surpassed by increased industrial energy demand, largely because of the rapidly growing importance of petrochemicals and petroleum refining. In any event, given the record of declining energy/output ratios in several of the countries throughout this period, it appears that some conservation measures have already taken place.

Industrial Energy/GNP Ratios

The left side of table 2-3 presents a cross-country comparison of energy consumption per dollar value of industrial output. Although such comparisons must be treated with caution--see appendix A--it appears that there is a very wide variation in the amount of energy consumed relative to industrial output among countries, including the three industrialized ones. Although there has been an apparent convergence of industrial energy/output ratios among many developing countries in the decade following 1967, it has not been enough to offset some wide variations which originally existed. India's industrial sector, for example, is at least two times more energy-intensive than any of the other developing countries listed. While these differences may have to do with the output of the industrial sector, the composition of the fuel mix also can frequently explain part of country variations. Indeed, it might be that since almost two-thirds of India's industrial energy demand is met by coal, frequently used in equipment yielding lower thermal efficiencies than other fuels, a large part of India's apparent industrial energy intensiveness is directly a result of its fuel mix.

Up to this point energy consumption data have been calculated in the traditional manner by which different fuels have been converted to the common unit of metric tons oil equivalent (toe) based on their calorific content. While it is physically correct that one calorie of coal is equivalent to one calorie of oil to one calorie of natural gas, the amount of "useful" energy in terms of end services performed which can be delivered from the various fuels, which is itself a function of both the fuels used and the appliances' efficiencies, does vary greatly. The use of non-adjusted consumption data may therefore mask actual trends of conservation efforts. Utilizing fuel efficiency factors may explain at least in part

the varying specific energy consumption statistics among countries with similar industrial sectors.

On the right side of table 2-3 useful industrial energy consumption/industrial GNP ratios, excluding the energy sector, are presented.[2] The center columns detail thermal energy/output ratios for non-energy industries. Although both data sets have a wide range of intensities, the cross-country differences decline by 30 percent, at least in 1976 when useful energy ratios are compared. Also, the developing countries with the highest thermal energy/GNP ratios--India, Mexico and Thailand--show the greatest change between those ratios and the derived useful energy ratios. In India the fall may be attributed primarily to its large, less energy-efficient coal usage; in Thailand to the importance of inefficient noncommercial fuels in the industrial sector; and in Mexico to the relatively minor role of electricity, the most fuel-efficient energy source.[3] In these developing countries as a whole, the percentage difference between the thermal energy/GNP and useful energy/GNP ratios is almost 30 percent. By contrast, the percentage differences in the three industrialized countries ratios are not nearly as large--less than 20 percent. The reason is that higher efficiency fuels, electricity and gas, play a much more important role in these well-developed industrial sectors than in the LDCs.

Industrial Electricity Demand

Of special interest is the record on electricity consumption in the industrial sector. While industry's demand for electricity as a percent-

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[2]See appendix A for the derivation of useful energy consumption, along with the specific thermal efficiency factors.

[3]There was no way to differentiate industrial electricity supplies which are generated from hydropower from those generated from fossil fuels. Had it been possible to include the heat losses associated with electricity production, the efficiency of electricity use would fall substantially. Thus, instead of an assumed 99 percent useful energy efficiency, the efficiency factor for electricity generated from fossil fuels would only be about 30 percent, since one unit of electricity output requires about three units of fossil fuel inputs. The efficiency of total electricity use would, in general, fall less in the developing countries than in the industrialized ones. This is due to the relatively much greater role played by hydroelectricity in the former and fossil fuel generated electricity in the latter.

age of total electricity consumed is not higher in the developing countries than in the industrialized ones (table 2-4), growth in industrial electricity demand has for the last decade generally outpaced that of developing countries' economies as a whole. The opposite pattern has held in the industrial countries. After the 1973 oil price rise, electricity consumption continued to expand--in some of these LDCs at an accelerated pace. Why then did electricity demand not fall with rising oil prices? First, in many developing countries dynamic overall industrial growth brought about rapid growth in industrial electricity demand throughout the 1967-1977 period; but electricity generating and transmission capacity was not able to expand rapidly enough to meet this growing demand--electricity consumption has been supply-constrained. As capacity increased so then did electricity consumption. Consequently, electricity demand has not been very elastic with respect to price changes. Second, and probably more important, real electricity prices have generally declined over this period, including since 1973 at both the wholesale and retail levels (Dunkerley, 1980b, p. 25). The reason is that oil-fired generation of electricity is a relatively small part of the total in many developing countries compared to that in the industrial countries. Rather, hydroelectricity, which was not subject to the price jump, remains a major electricity source. Indeed, hydro-abundant countries are generally well aware of their oil-saving resource as typified by the development pattern in Latin America. In 1960, 50 percent of the region's electricity generation was hydropower, but by 1975 it was closer to 60 percent (see table 2-5). Fuel oil typically supplies the bulk of the remaining requirements for generating base load, as it does for peaking, although many relatively small and high-cost diesel plants are also used. Hydropower is a preferred peaking fuel if water is available (Mullen, 1978, p. 59).

Additionally, in many developing countries wholesale industrial energy prices, including those of electricity, have been subsidized as part of an overall industrialization policy irrespective of potential impact on conservation measures. Such policies may in fact stem from the traditional perception of conservation noted earlier; that is, conserving energy reduces growth. Collectively these factors served to hold down electricity prices, which were then reduced even further in real terms due to high rates of inflation.

Table 2-4. Electricity Demand Growth Rates and Ratios of Industrial Electricity Consumption to Total Electricity Consumption
(percent)

	Growth of total electricity demand		Growth of industrial electricity demand		1977 Industrial elec. cons./ total elec. cons.
	1967-73	1973-77	1967-73	1973-77	
Brazil	11.3	12.1[a]	17.1	20.7[a]	47
Egypt	6.1	13.8	3.1	11.0	48
India	8.3	8.0	N.A.	9.2[a]	58
Kenya	9.9	6.5	N.A.	13.3	57
Korea	20.2	15.7	22.8	18.5	75
Mexico	11.5	8.4	12.4	10.7[a]	58
Nigeria	15.4	14.1	17.9	5.5[a]	45
Portugal	8.7	8.2	8.3	4.1	59
Thailand	20.4	11.6	N.A.	15.3	65
Turkey	15.1	9.4	15.8	10.4	73
United States	6.9	2.7	5.7	1.0	50
Germany	8.4	2.9	6.5	0.5	56
Italy	7.0	3.4	5.9	3.5	69
Japan	11.5	3.2	10.8	1.2	69

Note: N.A. = not available.

Source: International Energy Agency, Workshop on Energy Data of Developing Countries (Paris, OECD, 1979) and Energy Balances of OECD Countries (Paris, OECD) (various issues).

[a]Growth rate for 1973-76; industrial electricity consumption as a percent of total electricity consumption for 1976.

Table 2-5. Latin America: Electricity Generation by Sector and Country, 1950, 1960, and 1975 (GWH)

	1950			1960			1975		
	Hydro-electric	Thermal	Total	Hydro-electric	Thermal	Total	Hydro-electric	Thermal	Total
Argentina	183	5,120	5,303	927	9,531	10,458	5,197	24,272	29,469
Bahamas	--	16	16	--	76	76	--	660	660
Barbados	--	10	10	--	39	39	--	207	207
Bolivia	261	37	298	350	97	447	800	257	1,057
Brazil	7,198	1,010	8,208	18,384	4,481	22,865	73,836	6,457	80,293
Chile	1,649	1,294	2,943	2,977	1,615	4,592	6,135	2,597	8,732
Colombia	860	410	1,270	2,389	1,131	3,520	9,849	4,750	14,599
Costa Rica	175	7	182	392	46	438	1,269	224	1,493
Cuba	14	1,280	1,294	20	2,961	2,981	62	6,521	6,583
Ecuador	72	80	152	175	214	389	647	1,201	1,848
El Salvador	40	48	88	240	16	256	401	625	1,026
Grenada	--	1	1	--	4	4	--	27	27
Guatemala	83	33	116	143	167	310	282	835	1,117
Guyana	--	38	38	--	90	90	--	384	384
Haita	--	38	38	--	90	90	145	39	184
Honduras	6	44	50	19	78	97	420	120	540
Jamaica	50	70	120	126	384	510	131	2,140	2,271
Mexico	1,950	2,474	4,424	5,149	5,579	10,728	15,076	28,430	43,506

Table 2-5 (continued)

Nicaragua	35	45	80	45	131	176	404	514	918
Panama	5	99	104	18	216	234	97	1,123	1,220
Paraguay	--	40	40	--	96	96	523	69	592
Peru	710	110	820	1,794	854	2,648	5,522	2,174	7,696
Dominican Republic	--	79	79	--	349	349	194	1,438	1,632
Surinam	--	35	35	--	79	79	1,020	580	1,600
Trinidad & Tobago	--	160	160	--	470	470	--	1,220	1,220
Uruguay	527	89	616	676	568	1,244	1,132	1,312	2,444
Venezuela	174	479	1,153	95	4,475	4,570	8,912	12,267	21,179
LATIN AMERICA	13,992	13,611	27,603	33,919	33,758	67,677	130,840	98,425	229,265

Source: Joseph W. Mullen, Energy in Latin America: The Historical Record (Santiago, Chile, Commission Economique Pour l'Amerique Latine (CEPAL), 1978) p. 55.

Table 2-6. Ratios[a] of Electricity Consumption Index/Production Index for Various Manufacturing Sectors (1970 = 100)

	1963	1967/68	1973	1974	1975	1976	1977
Brazil							
Food	--	116	104	108	113	112	118
Textiles	--	98	97	106	105	105	101
Paper	--	95	103	110	130	121	119
Chemicals	--	97	104	108	115	114	116
Iron and steel	--	102	115	126	118	129	130
All manufacturing	--	104	101	104	104	106	114
Colombia							
Food	96	72	75	80	71	74	--
Textiles	95	90	85	98	99	96	--
Paper	122	108	83	108	99	114	--
Chemicals	162	167	246	188	225	265	--
Petroleum refining	102	95	142	114	123	139	--
Iron and steel	56	102	118	145	156	147	--
All manufacturing	97	110	106	110	111	111	--
Dominican Republic							
Food		101	122	120	127	115	122
Textiles	149	131	146	149	115	103	149
Paper	46	129	81	147	200	164	107
Chemicals	109	121	79	78	58	52	51
All manufacturing	112	94	109	111	106	101	109
Ecuador							
Food	94	83	105	101	109	146	--
Textiles	103	95	89	103	96	103	--
Petroleum refining	104	89	89	77	71	63	--
All manufacturing	96	94	105	101	105	113	--
El Salvador							
Food	--	--	147	134	142	--	--
Textiles	--	--	108	127	130	--	--
All manufacturing	--	--	114	128	120	--	--
Korea[b]							
Food	--	--	108	122	123	107	97
Textiles	--	--	107	122	125	113	123
Paper	--	--	95	100	103	100	94
Chemicals	--	--	98	96	91	78	74
Iron and steel	--	--	87	68	72	68	67
All manufacturing	--	--	97	88	86	76	78

Table 2-6 (continued)

	1963	1967/68	1973	1974	1975	1976	1977
Mexico							
Food	--	97	94	101	95	108	--
Textiles	--	--	86	87	85	91	--
Paper	--	97	100	92	98	91	--
Chemicals	--	--	94	107	111	117	--
Iron and steel	--	93	99	97	101	106	--
Philippines							
Food	--	82	164	146	--	--	--
Textiles	--	92	93	124	--	--	--
Paper	--	80	265	251	--	--	--
Chemicals	--	161	106	60	--	--	--
All manufacturing	--	87	135	145	--	--	--
Portugal							
Food	--	81	122	116	113	112	114
Textiles	87	102	90	89	91	93	102
Paper	86	100	105	88	77	91	85
Chemicals	--	138	255	313	335	247	274
Iron and steel	85	87	101	116	141	119	132
All manufacturing	86	111	121	127	129	126	141
Tunisia							
Textiles	--	125	122	184	224	267	--
Paper	--	--	419	557	313	326	--
Chemicals	--	26	101	138	107	146	--
All manufacturing	--	53	129	157	148	160	--

Source: United Nations, Growth of the World Industry, vol. 1 (New York, UN) (various issues) and Yearbook of Industrial Statistics, 1977 Edition, vol. 1 (New York, UN, 1979).

[a]Index of electricity consumed in each sector divided by the index of industrial production for each sector where the base is 1970 and the resulting index ratio for 1970 = 100. The ratios measure the change of electricity consumption per unit of industrial production relative to the consumption/output relationships in 1970.

[b]Base year is 1972 = 100.

Given the decline in real energy prices and the dramatic increases of electricity demand in the industrial sector as a whole, it is not surprising to find that in many developing countries the electricity output per unit of output has risen in the individual manufacturing industries for which data are available. Once again, the proper caveats must be made with respect to the data,[4] but even then the trends are significant enough to be illustrative. Specific industries will be discussed in chapter 4. At this point it is important simply to note that all countries listed in table 2-6, except Korea, experienced increased electricity use per unit of total industrial output from the 1960s/early 1970s forward. Korea, by contrast, without significant domestic petroleum or hydro resources, had a declining electricity/production ratio in most manufacturing industries. Available data for all ten countries show that electricity consumption per unit output was generally increasing in the food and textile industries (improvements in worker comfort and mechanical packaging), the iron and steel industry (expansion of electric arc furnace use), and industrial chemicals (rapidly expanding output), while trends in petroleum refining and paper industries are mixed.

This paper does not outline the various measures which might prove successful in reducing energy inputs for generating electricity, or even detail the differences among countries. Certainly the potential savings are substantial in both electricity transformation and transmission. Transformation losses in developing countries generally are significantly higher than those in industrial countries, while transmission losses vary greatly even among the LDCs--from as low as 7 percent in Taiwan (Chen, 1977, p. 14) up to 35 percent in parts of India (Reddy and Prasad, 1977, p. 1473). In the United States such losses are estimated at about 7 percent (ECE 1976, p. 61). Rather, the preceding has detailed the dramatic rise in electricity use by the industrial sectors of many developing countries, and the apparently increasing intensity of use in specific manufacturing industries. While the decision to purchase electricity is a function of complex factors--fuel prices and availability, regulatory policies, production processes, plant size and own-use generating possi-

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[4] Appendix B discusses collection techniques and problems encountered in tabulating electricity consumption data.

bilities--there are indications that electricity might be used more efficiently. For example, estimates indicate that such measures as economy in use of air conditioning and lighting, production scheduling for minimizing energy consumption at peak hours and seasons, avoidance of idle running of machines, and improved plant maintenance to avoid waste in various electrolysis, electrolytic and electronic processes, might immediately save 5-10 percent in India (Bose, 1977, p. 13). For some countries, in some sectors, electricity savings could be even larger.

Conclusions

This chapter has briefly summarized aggregate industrial energy use patterns in several developing countries. Comparisons with trends in four industrial countries were made. Prior to the oil price rise, industrial energy demand was growing rapidly in all countries. After 1973 this growth fell significantly in the developed economies, but not nearly so much in the developing countries. At least part of the explanation for the decline in industrial countries' energy use is that industrial output tended to stabilize, a development which did not occur in the LDCs reviewed. Their continued expansion of industrial production meant increasing energy requirements although changes in energy consumed per unit of output varied among countries. For most developing countries such unit energy use in 1976/77 was above 1973 levels.

Energy consumption per million dollars of industrial output also varies greatly among countries. Part of the explanation is the output mix, but at least part is explained by the relatively greater use of thermally inefficient fuels in developing countries than in industrialized ones. Structural differences are addressed in chapter 3.

Industrial electricity demand was also reviewed, revealing much faster growth rates in developing economies than in well-developed ones. As is the case of total energy demand, electricity consumption continued to expand rapidly after 1973. The large role of hydroelectricity and declining real electricity prices provide the bulk of the explanation. Consequently, electricity consumption per unit of output in most manufacturing industries appears to be rising. Significant conservation potential would seem to exist.

Chapter 3

INDUSTRIAL STRUCTURE AND ENERGY DEMAND

We noted previously that industrial energy demand is a function of the absolute size of the industrial sector, the structure of output and the energy intensity of production. Chapter 2 reviewed the absolute changes in energy demand as it relates to changes in size of industrial output. Chapter 4 looks at the energy intensity of production in several manufacturing subsectors. In this chapter we look at the structure of industrial output in four developing countries--Brazil, India, Korea and Kenya--and its implications for industrial energy demand.

The selection of these four countries provides interesting cross-comparisons perhaps typifying many other developing countries. The data presented in table 3-1 show that the structures of their economies and industrial sectors are quite diverse:

- o Brazil is a high income developing country with a large, well-established industrial sector. Its total industrial output is two and one-half times larger than India's, five times Korea's, and seventy-six times the size of Kenya's.

- o India is a low income country (only $190 per capita) with a large, but rather slowly growing industrial sector.

- o Kenya is also a low income country with, by contrast, a small industrial sector. Its industrial output does not contribute significantly to total GDP.

- o Korea is a rapidly growing high income developing country like Brazil. Its industrial sector, however, is extremely new as indicated by a quadrupling of physical output over the 1970-77 period.

Table 3-1. Structure of Economies of Four Developing Countries

	1977 GDP per capita (1977 US $)	Percent of 1977 GDP by industry (%)	1977 industrial GDP (millions of 1977 US $)	Rate of industrial growth (1967-77) (%)
Brazil	1,410	26	42,609	11
India	160	[a]18	[a]16,880	5
Kenya	290	13	560	8
Korea	980	30	10,546	23

Source: World Bank, Atlas (Washington, D.C., 1979); United Nations, Statistical Yearbook (New York, 1978)(various issues); World Bank data services.

[a]Data are for 1976.

As noted in chapter 2, total industrial energy demand varies greatly among countries, as is also clear in these four countries. Table 3-2 shows that India's total industrial energy demand from the mid-1960s to the mid-1970s is by far the largest at 43 million metric tons oil equivalent (toe) in 1976. Brazil's consumption was only three-fifths this, 26 million toe, although its industrial energy demand has been growing more rapidly than India's.[1] Korea's rapid energy demand growth of 20 percent per year over this period still results in total demand at but one-eighth of India's. Kenya's total demand is less than one-tenth of Korea's, only .45 million toe.

How much of these differences are a result of different structures of their economies? For the purpose of this chapter structure of the industrial sector refers not only to the product mix of total industrial output, but also to the mix of fuels consumed. Also, there are several levels at which industrial structure may be analyzed.

[1]The derivation of industrial consumption for India, Kenya and Brazil is presented in appendix A. Korea's industrial energy demand is obtained from Philippe Bourcier, 1979.

Table 3-2. Industrial Energy Demand for Fuel Source[a]
(000 metric tons oil equivalent)

	1967	1976
Brazil		
Total	10,975	25,920
Petroleum	6,036	15,618
Coal	934	1,833
Gas	383	700
Electricity	797	3,603
Noncommercial	2,825	4,166
India		
Total	24,211	43,342
Petroleum	4,159	4,968
Coal	19,018	31,501
Gas	84	829
Electricity	172	4,383
Noncommercial	778	1,661
Kenya		
Total	120	452
Petroleum	96	347
Coal	2	2
Gas	--	--
Electricity	--	43
Noncommercial	22	60
Korea[b]		
Total	1,271	5,412
Petroleum	640	4,146
Coal	417	251
Gas	--	--
Electricity	214	1,015
Noncommercial	--	--

Source: International Energy Agency, Workshop on Energy Data of Developing Countries (Paris, OECD, 1979); Philippe Bourcier, "Energy," in Korea (Baltimore, Johns Hopkins University Press, 1979) p. 283.

[a]Data include the energy sector's own use, but not transformation losses.

[b]Korean data for 1966 and 1974 and it is not clear whether own use of energy in the power generating sector is included in totals.

Table 3-3. Comparisons of Industrial Structure and Industrial Energy Demand[a] for 1976

	Percentage of GDP originating in the industrial sector (%)	Percentage of total energy consumed by the industrial sector[a] (%)	Industrial energy consumption	
			Metric tons oil equivalent per million $ 1977 GNP	Metric tons oil equivalent per million $ 1977 industrial GNP
Brazil	[b]26	24	165	612
India	18	34	462	2,568
Kenya	14	10	113	871
Korea[c]	30	36	208	693

Source: International Energy Agency, Workshop on Energy Data of Developing Countries (Paris, OECD, 1979); Philippe Bourcier, "Energy," in Korea (Baltimore, Johns Hopkins University Press, 1979); industrial output derived from World Bank data services and United Nations, Statistical Yearbook (New York, UN) (various issues).

[a]Includes the energy sector.

[b]Data for 1977.

[c]Data for 1974.

As shown in table 3-3, Korea is the most industrialized of these four countries, with 30 percent of the value of its total GNP output originating in the industrial sector. Accordingly, its industrial energy consumption/GNP ratio (208 toe million $) is slightly higher than Brazil's (165) where 26 percent of GNP comes from industry; and almost double the Kenyan ratio (113) which might have been expected given the fact industrial output contributes only 14 percent to Kenya's total Gross National Product. Indeed, at this aggregate level India stands out as the anomaly since its industrial energy consumption/GNP ratio is 462 toe despite the fact that industry's contribution to GNP is only 18 percent.

Again, making a simple comparison between the percentage of total energy consumed by industry and industrial GNP we find that India is the anomaly. In percentage terms of the appropriate totals, Brazil's and Kenya's industrial energy consumption is only slightly below their indus-

trial production while Korea's industrial energy consumption (36 percent) is somewhat greater than total industrial output (30 percent). In India, however, 34 percent of total energy demanded is used by industry, whereas industry produces only 18 percent of GNP. As a result, India's industrial energy consumption/industrial output ratio is three to four times larger than the ratios of the other three countries. In contrast, Kenya's industrial energy/output ratio (871 toe/million $) is by far larger than either Korea's or Brazil's despite its industrial energy consumption being both relatively and absolutely smaller than theirs.

Comparisons of Structural Trends

Perhaps table 3-4 most simply captures the result of structural influences on energy demand. Between 1967-76 Korea's industrial output was growing quite rapidly (23 percent) which entailed comparable energy growth (20 percent). Yet Kenya, a slow growth country (8 percent), also experienced rapid increases in total industrial energy consumption (16 percent). While India's industrial output was also growing only slowly, something was causing its requisite energy inputs to be higher than were necessitated in past output. Brazil's industry grew rather rapidly, and yet, like Korea, energy inputs did not rise as fast as output. The possible explanations for these differences among countries will now be explored in more detail.

The trend in all four countries since the mid-1960s has been that a declining proportion of manufacturing output has been from light industries, while heavy industries have been of growing importance (table 3-5). This trend has been most pronounced in Korea and then India, but less so in Brazil and Kenya. While heavy industries generally require more energy inputs per unit output than do light industries,[2] comparisons of these trends with ratios of industrial energy consumption/dollar value of industrial output (table 3-4) over the 1967-76 period provide a mixed record. In two of the countries--India and Kenya--the ratios increased, while in

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[2]The question of energy intensities is explored in much greater detail in chapter 4. At this point it is sufficient to note that heavy industries on the whole require greater energy inputs per ton or dollar value of output than do light industries. Table 4-2 providing energy input/output coefficients for the United States illustrates this point.

Table 3-4. Rate of Growth for Industrial Output and Industrial Energy Demand, 1967-76

	1967-76 Rate of growth of		Industrial energy consumption/ Industrial output ratio	
	industrial output (%)	industrial energy demand (%)	1967	1976
			(toe $ million 1977 output)	
Brazil	11	10	804	612
India	5	7	2,367	2,568
Kenya	[a]8	16	391	871
Korea[b]	23	20	781	693

Source: Philippe Bourcier, "Energy," in Korea (Baltimor , Johns Hopkins University Press, 1979); International Energy Agency, Workshop on Energy Data of Developing Countries (Paris, OECD, 1979); United Nations, Yearbook of Industrial Statistics, 1977 edition, vol. I (New York, UN, 1979).

[a]Manufacturing sector only.

[b]Data for 1966-74.

the other two the ratio declined. That is, over this ten year period, for every dollar increase in industrial output India and Kenya used an increasing amount of energy. Production in Brazil and Korea required less energy per dollar's worth of output in the mid-1970s than it had in the 1960s.

In more detail that the heavy/light industry classification, table 3-6 provides in percentage terms the general distribution of several industries' contribution to total manufacturing value added. Although comparable manufacturing subsector energy demand data are not available, a review of the internal structure of a country's industrial sector provides some insight concerning the differences in industrial energy demand both among countries and over time. These are enumerated in the following country sections.

Table 3-5. Light and Heavy Manufacturing Industry--Selected Countries (percentage)

	Mid-60s		Mid-70s	
	Heavy	Light	Heavy	Light
Brazil				
Value added	54.7	45.3	62.8	37.2
Gross output	50.3	49.7	61.3	38.7
Korea				
Value added	35.5	64.5	48.6	51.4
Gross output	37.2	62.8	51.3	48.7
India				
Value added	49.9	50.1	60.4	39.6
Gross output	N.A.	N.A.	59.5	40.5
Kenya				
Value added	37.4	62.6	45.0	55.0
Gross output	28.3	71.7	33.9	66.1

Note: N.A. = not available.

Source: United Nations, The Growth of World Industry, 1970 Edition (New York, UN, 1972); United Nations, Yearbook of Industrial Statistics, 1977 edition, vol. I (New York, UN, 1979); United Nations Industrial Development Organization (UNIDO), World Industry Since 1960: Progress and Projects (New York, UN, 1979).

Korea

Among the countries reviewed, structural shifts were by far largest in the Republic of Korea when only the aggregate light/heavy industry classification was used. When manufacturing subsectors are reviewed the trend is not as apparent. Over the 1968-76 period less energy-intensive light industries--food, beverages, tobacco and textiles--fell by 4 percentage points in relative importance to total output, while the heavier and more energy-intensive machinery and equipment industries grew significantly in relative importance. The most energy-intensive industries--chemicals, petroleum refineries and basic metals--maintained their relative importance in total manufacturing value added over the period. Yet at the same time total in-

Table 3-6. Percent of Total Manufacturing Values Added Originating in Several Manufacturing Subsectors (percentage)

	Brazil		India		Kenya		Korea	
	1968	1974	1968	1976	1968	1976	1968	1976
Food products	12	10	9	9	16	33	7	7
Beverages, tobacco	4	3	3	3	14	13	16	12
Textiles	11	8	22	17	8	5	16	16
Machinery & equipment	20	22	21	23	18	12	10	17
Paper & products	3	4	2	2	2	4	3	2
Industrial chemicals	11	11	13	7	7	3	8	5
Other chemicals	6	4	a	8	a	8	5	5
Petroleum refineries	a	a	2	2	7	b	4	6
Iron & steel	[illegible]	[illegible]	10	11	--	[illegible]	3	5
Nonferrous metals	12	14	2	2	--	1	1	1
Metal products	[illegible]	[illegible]	3	3	7	4	3	2
Other	21	24	13	13	21	17	23	22

Source: United Nations, Yearbook of Industrial Statistics, vol. I, 1977 edition (New York, UN, 1979); and Growth of World Industry, vol. I, 1973 edition (New York, UN, 1975).

[a]Included in industrial chemicals.

[b]Included in other chemicals.

dustrial output has been growing dramatically, equating to a sevenfold increase over this period.[3]

Despite the comparatively large domestic market of the Republic of Korea, the extent of its reliance on export-led growth is unique among the countries considered here. During most of the period shown, export expansion accounted for 38 percent of manufacturing growth while import replacement contributed only 2 percent (UNIDO, 1979, pp. 95-96). Manufactured exports of engineering and metal products and of textiles are substantial. The success of these exports is reflected in the relatively high shares recorded in table 3-6 for textiles, iron and steel, electrical machinery and transport equipment.

At the same time industrial energy demand is rather low relative to the other three countries. An important explanation would appear to rest with the fact that its industrial sector was growing so rapidly during the period when energy prices were rising. Direct and indirect energy costs as a fraction of the total cost of producing these materials have recently risen to the point where energy is now a major cost element (see table 3-7). Consequently, such newly industrializing countries as Korea benefit from installing newer technologies with significant economies in energy consumption--especially in the energy-intensive heavy industries--compared with slower growing more industrialized countries where energy savings are more constrained by the existence of large prior capital investments.

The Republic of Korea apparently achieved substantial energy economies in the few years following the price increases of the early 1970s. This seems to have occurred largely in industries where energy is used principally for materials forming, cutting and handling[4]--metals fabrication, machinery and equipment manufacture--precisely the industries which have grown in relatively greatest importance. However, many other sectors have also benefited from new industrial stock as exemplified by the fact that Korea's textile industry is largely modern, with almost 50 percent of the spindles and looms having been installed within the past five years.

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[3]The detail of industrial output growth is largely obtained from United Nations Yearbook of Industrial Statistics.

[4]"Industrial Growth Options and Energy Use in Developing Countries," unpublished paper by Alan M. Strout.

Table 3-7. Ratio of Energy Costs to Total Production Costs in Korea (percentage)

	1973	1975
Manufacturing	4.6	6.7
Steel	4.6	16.5
Nonferrous metals	6.5	10.1
Machinery	3.2	2.5
Chemical industry	7.3	5.5
Petrochemicals	2.8	3.3
Synthetics	4.1	6.9
Pulp & paper (chemical)	9.9	12.8
Textiles	N.A.	5.0

Note: N.A. = not available.

Source: Korea Development Institute, Long-Term Prospects for Economic and Social Development 1977-91 (Seoul, Korea, KDI, 1978).

Additionally, the Korean government's response to the oil crisis has been quite impressive: prices of petroleum products were increased in line with international prices in contrast to previous policies of subsidizing energy prices in order to promote industrial development. Also, a comprehensive energy conservation program was launched in November 1973 and was then followed by additional measures in October 1974 and January 1975. Under the provision of the Heat Management Law (HML) the program's objective is for 10 percent fuel conservation in industry and power generation. The HML provides training in heat management, establishes energy consumption standards and inspects industrial plants for implementation of energy conservation techniques.

To summarize, the structure of industrial output has been of less importance to Korea's industrial energy demand than has been the process of rapid development itself. Rapid growth in many energy-intensive industries

resulted in significant increases in industrial energy demand. However, the reliance on newer energy-saving equipment left Korea's energy consumption/industrial output ratio (despite the changing structure) rather stable. Government policies also encouraged industrial energy conservation.

Brazil

Of the countries considered, Brazil has the advantage of a large domestic market and one of the highest incomes in Latin America. Import substitution and domestic market expansion have been closely associated with policy formulation throughout much of the postwar era. The encouragement of heavy industry has been an important element in the country's overall policy of import replacement. Consequently, the share of light industry in total manufacturing value added is the lowest among the countries reviewed --37 percent.

During the period 1967-1976 the industrial sector of Brazil expanded at an exceptionally rapid pace: 11 percent per annum. Production was diversified to encompass certain capital goods and sophisticated consumer durables. Simultaneously, the emphasis of industrial policy was broadened to include some specific export promotion policies. As of 1977, the industrial policy of Brazil was focused on iron and steel, nonferrous metals, cement and petrochemicals--all heavy industries. In addition, the capital goods industry had been identified as a braod sector in which import substitution was a major goal.

As in the case of Korea, fast industrial growth, especially in the heavy industries, required large increases in energy (table 3-2). Also as in Korea, rapid industrialization allowed the increasing use of energy-efficient capital equipment so that total industrial energy demand rose less than might have been expected given its fourfold increase in steel and aluminum production, and a threefold increase in both cement production and petroleum refining between 1967-1977.

However, what is most curious is that, although industrial energy consumption has continued to rise sharply, the ratio of industrial energy consumption to industrial output has actually been declining over the last ten years. (In Korea it remained rather stable.) The energy/GDP ratio was

on the rise in most industrial countries during the 1960s, and it seems unlikely that the figures reflect a special Brazilian bent for energy efficiency. A more likely explanation is that as commercial fuels replaced less efficient noncommercial fuels, there occurred a one-time rise in apparent energy efficiency (Erickson, 1980, pp. 1-7). The degree to which this might be the case cannot readily be ascertained, since, as detailed in table 3-2, noncommercial fuels consumption was rising during the 1967-76 period (4 percent/year), although at a pace much slower than total industrial energy demand (10 percent/year).

In addition to this effect of declining noncommercial fuel use on total industrial energy demand, improvements in Brazil's energy/output ratio may also be attributed to greater utilization of energy saving equipment, especially in just a few industries. By 1979, the cement industry consumed 20 percent of all the fuel oil used in Brazil, far surpassing its nearest competitors: petroleum refining (14 percent), steel (11 percent), and petrochemicals (11 percent). It will also be recalled from table 3-6 that the single largest manufacturing subsector, machinery and equipment, has also grown significantly over the last decade. Since these are two of the least energy-intensive heavy industries, the growth in total industrial output may have indeed required less than a comparable rate of growth in industrial energy demand--therefore the declining energy/output ratio.

The second oil shock prompted President João Baptista Figueiredo in July 1979 to warn that new oil prices would force his government to adopt measures similar to those of a "war economy." As a result, the National Energy Commission was created in July 1979. Goals include increased domestic production of petroleum products, pushing ahead in the harnessing of Brazil's rich hydroelectric potential, and major increases in coal production so that coal can replace fuel oil, particularly in such industries as cement production.[5] The government also pressed ahead in its desire to substitute alcohol for petroleum feedstocks in the chemical industry.

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[5]Consequently, the government goal is to get Brazilian industries to accept the coal, and in September 1979 officials took a major step in this direction. The ministers of industry and commerce, of mines and energy, and of transportation signed an agreement with the presidents of the *sindicatos* (associations) of cement and coal mining firms to begin substituting coal for fuel oil in the cement industry. The cement industry will pro-

Like Korea, Brazil has a very large industrial base which has been expanding steadily. The structure of production emphasizes the energy-intensive industries and will continue to do so. This has entailed large increases in industrial energy requirements. Yet the use of newer energy-saving technology coupled with a decreasing reliance on energy-inefficient noncommercial fuels has resulted in declining industrial energy/output ratios; lower than the other three countries being reviewed.

Recent government policies reflect a growing awareness of the need for industrial conservation measures given the energy-intensive structure of output and the large dependence of Brazil's industrial sector on imported oil.

India

The industrial structure of India with its large domestic market is characterized by a wide range of activities. The basic pattern of structural change, starting in the 1950s and continuing into the 1970s, was an increasing role for capital goods industries which expanded mainly at the expense of agro-based light industries. The share of light industries declined from 50 percent in the mid-1960s to 40 percent ten years later.

The performance of different industries has varied considerably. Among the more dynamic have been basic industrial chemicals, pharmaceuticals, paper and paper products, engineering goods and silk and rayon textiles. The growth in basic industries such as iron and steel and cement has sometimes lagged. Beginning as early as 1956 with the Industrial Policy Resolution, the government stressed heavy industry growth with the public sector taking a leading part. State participation has varied among branches from that of sole responsibility (iron and steel, heavy electrical machinery, aircraft and shipbuilding) to that of simply taking the initiative in the creation of new industries (machine tools, chemicals, fertilizers, synthetic rubber, etc.). Policy now seems to have shifted from an emphasis on heavy industry as the prime engine of growth to rural development and small-scale and cottage industries (UNIDO, 1979, pp. 91-94).

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gressively increase its coal consumption, according to an agreed-upon timetable, and, during the transition, government subsidies will neutralize fuel-price differences among firms in the sector (Erickson, 1980, p. 36).

As noted earlier, India's industrial energy consumption is extremely large (34 percent of total energy demand), especially considering the relatively small role of industry in overall economic activity (18 percent). Also, the Indian industries' energy requirements per dollar of output are far larger than those of the other three countries being reviewed. One important explanation for this high industrial energy demand would appear to center on the fuel composition of industrial energy demand. Since India has abundant coal resources most industries developed by utilizing coal as their energy source. In fact, the worldwide trend to oil use in the post-war period generally did not occur in the Indian industrial sector. Up until 1970 the share of coal in total industrial energy consumption was actually rising. This was at least partly because of the change in the industry mix; there was rapid expansion in such coal-using industries as steel and cement in the late fifties. In the sixties there was a small but distinct shift to oil. An expansion of domestic oil refining made available increasing quantities of furnace oil that were absorbed by industry as well as by power plants. However, most oil resources had to be imported so that after the 1973 oil price rise much of these supplies could no longer be afforded.

The industrial sector was considered by the Indian government to be particularly susceptible to cutbacks in oil consumption through coal utilization. By and large, the government relied on the rises in petroleum product prices, reinforced by taxes, to restrain oil consumption. However, since energy costs constituted only a small proportion of many industries' total costs, it was believed that the industrial demand for furnace oil would be inelastic. Hence, physical allocation was resorted to. By 1976 coal accounted for 73 percent of total industrial energy demand, down only slightly from the 79 percent share it held in 1967. Industrial petroleum consumption actually declined to only 11 percent of the total from its 17 percent share ten years earlier (see table 3-2).

The significance of the dominant role of coal in the industrial sector is that coal is generally used in less efficient industrial boilers than is petroleum resulting in higher requisite energy inputs. One study has shown that enormous amounts of energy used in industry are discarded as waste heat and that, with some exceptions, there is evidence that the efficiency

of energy use has not been of concern to industries (Ramachandran, 1977, p. 385). The production of primary metals, basic chemicals, petroleum products, food, paper, glass, and concrete account for a substantial portion of the energy consumed in the industrial sector. Coal is used to a large extent in all of these industries, including petroleum refining.

While it is government policy to encourage the use of coal in furnaces and boilers rather than fuel oils as a result of India's resource endowment, this policy is being matched by encouraging greater efficiency of coal use. The National Productivity Council has been identified as the agency for providing services such as surveys of industrial energy utilization and industrial establishment energy audits.

Two other factors might also have resulted in the apparently high industrial energy output ratios in India. First, heavy energy-intensive industries comprise the bulk of industrial output. Since most of these industries have been growing only slowly, the opportunities for substituting old production equipment with newer, more energy-efficient capital has not been nearly as great as, for example, in Korea and Brazil.

Second, at least some measure of explanation is provided by the makeup of many Indian manufacturing subsectors. There is an extremely large number of small and old establishments, especially in the light industries, which might suggest serious diseconomies of scale when one is considering energy usage. Textiles accounted for almost 17 percent of India's 1976 manufacturing fuel oil consumption, which is more than that used by any other industry except chemicals (Desai, 1979, p. 21). Up until recently government policy had not been to encourage modernizing investments which might have resulted in increased energy efficiency in these small establishments.

The important role of coal and the development of heavy industries explain most of India's high industrial energy consumption. The current government policy of placing renewed emphasis on agro-based and light industries, coupled with this continued importance of coal, will most likely determine future industrial energy demand.

Kenya

The manufacturing sector in Kenya has been diversifying, but by 1976 manufacturing value added had amounted to only 17 percent of GDP. Textiles

and leather products have been the most dynamic as have rubber and metal products. Petroleum refining has also expanded somewhat over the last decade.

Kenya's 1974-78 development plan foresaw a 10.1 percent annual growth in manufacturing output, but this was attained only once, in 1976. These were years of weak domestic demand and high inflation. Food processing, footwear, textiles and clothing have together provided about 45 percent of manufacturing output in recent years, although they have suffered from periodic problems. In the case of food processing, droughts affecting agriculture have upset growth plans. Clothes and textiles have suffered from severe excess capacity, brought about by a depressed home market, cheap imports and interruptions in the foreign supply of cotton inputs. Despite this excess supply, the 1974-78 plan envisaged major investments in textiles, along with fertilizers and metal semimanufactured goods. Paper output nearly doubled between 1972 and 1975 and a new mill was opened in 1975 (UNIDO, 1979, pp. 100-101).

What is most noticeable about the structure of Kenya's industrial sector is its large contribution of food products to value of output: 33 percent in 1976. More generally, light industries as a whole accounted for 55 percent of industries' value added. Normally, such a structure emphasizing light industries would require less energy than when heavy industries dominate, and in fact Kenya's industrial energy consumption is quite small relative to both the other three countries' industrial energy demand and to its own distribution of total energy consumption. Only 10 percent of its total energy demand was consumed by industry. Yet, Kenya's energy consumption of 871 toe per million dollars of industrial output is second only to India's ratio. Brazil's and Korea's requisite energy inputs per million dollars of output are much lower, 612 toe and 693 toe, respectively (table 3-4). What then explains Kenya's relatively high energy requirements?

Petroleum refining is very important in Kenya's industrial sector, 8 percent of total value added. Yet, although the data are scarce, it appears that about 25 percent of industrial commercial energy demand is used by petroleum refineries. In addition to the large energy inputs required in petroleum refining, Kenya's East African Oil Refinery increased its size

after 1973 but did not increase output. Consequently, efficiency fell and is reflected by apparently high overall industrial energy demands relative to output.

Two other factors may have also contributed to Kenya's relatively high energy requirements. First, food processing has suffered in recent years from droughts while textiles have suffered from severe excess capacity. Given the important role of these industries in total industrial output and the indivisibilities in energy-using equipment, unusually high energy requirements may have resulted. Second, less efficient noncommercial fuels such as fuelwood have been extremely important in total industrial energy supplies. In 1976 they accounted for 13 percent of the total. For example, it is reported that one manufacturer of food and household items had only recently hired an engineer to make process modifications to reduce energy use, in addition to eliminating the use of firewood (Schipper, 1980, p. 4). Government policy now aims to conserve wood for uses other than process heat and so the role of noncommercial fuels in industry should decline.

Despite relatively slow overall growth in Kenya's industrial sector, industrial energy demand has grown at a much faster pace. The dominant role of light industries, especially food processing, would seem at first glance to be contradictory to such a development. The role of petroleum and the importance of noncommercial fuels help explain the contradiction. In addition, depressed demand and excess manufacturing capacity may explain in part Kenya's large industrial energy demand growth.

Conclusions

The record was found to be quite mixed among Korea, Brazil, India and Kenya with regard to structural characteristics and their effects on industrial energy demand. Korea, which experienced the most rapid rate of industrialization and, more specifically, the most rapid change in emphasizing the energy-intensive heavy industries over light industries, had the fastest growth rate of industrial energy demand, 20 percent--though much slower than its growth rate of industrial output. Yet in Kenya where all industries, especially heavy ones, have grown relatively slowly, industrial

energy demand grew at an annual 16 percent rate between 1967-76. In Brazil and India industrial energy demand grew in tandem with their respective industrial output. In all four countries the size of the industrial sector is, as expected, directly related to the size of industrial energy demand.

In Korea, the utilization of newer energy-efficient equipment appears to have been more important than the actual structure of industrial output although emphasis on heavy industries also helps determine energy demand. In Brazil, industrial growth rates have been accompanied by only comparable energy demand increases despite the greater role of heavy industries in total output. Partial explanation is that machinery and equipment, two of the least energy-intensive heavy industries, have been the most dynamic sectors. The declining relative importance of noncommercial fuels in industry also explains the softening of energy requirements despite rapid industrial growth.

In India the structure of fuel sources--namely the high dependence on coal--appears more significant in explaining industrial energy demand than does the structure of its output mix. Coal usage will continue to be encouraged as will a renewed emphasis on light agro-based industries. The structure of industrial output in Kenya's energy demand is significant primarily because petroleum refineries require an abnormally large percentage of total energy consumption. As in Brazil, the structure of energy supplies may also be an explanatory factor in its energy/output ratio since noncommercial fuels make up 13 percent of total industrial energy supplies.

Chapter 4

MANUFACTURING PROCESSES AND ENERGY INTENSITY

We noted at the outset that the energy intensity of industrial output--that is, units of energy inputs required to produce units of physical output--has significant implications for total energy demand and for conservation opportunities. Not only is the choice or structure of industrial output important, but so also is the choice of production process and the efficiency of production. Many believe that reductions in industry's energy intensity might result in significant energy savings. Reductions, it will be recalled, do not mean energy conservation through physical reductions in output. Rather, given a certain output, changes/improvements in production activities or processes may result in less energy being consumed to produce this output than would have been the case had these changes/improvements not taken place.

Energy intensities vary both among and within industries. The manufacturing of aluminum is known to be more energy-intensive than the manufacturing of steel. Within steelmaking itself there are several different technologies, each with its own minimum energy requirement. Similarly, several plants using the same steelmaking technology may have different energy intensities of production resulting from varying ages of plants, capacity utilizations and management techniques. Conservation measures are believed possible in all these determinants of production efficiency. In the United States, for example, it is estimated that such intensity conservation measures, with present technology, could result in 40 percent energy savings, the bulk coming through the replacement of primary process facilities in chemical. steel, aluminum and paper industries (CONAES,

1979a, p. 106). To date, however, we have seen that most industrial energy savings have been attributed to "housekeeping" measures.

In Europe about 50 percent of total industrial energy demand is generated by three highly energy-intensive industries--iron and steel, chemicals, and aluminum. As a result, the pattern of energy demand and conservation potential has been heavily influenced by the process technology of these three industries (ECE, 1976, p. 65).

While the specific source and means of conservation potential varies within each manufacturing subsector, it is the process steam and direct heat applications which offer the greatest opportunities for energy savings. Together these two energy activities account for approximately two-thirds of total industrial energy inputs. The remaining one-third is accounted for by electricity, 26 percent--mostly for heating, lighting and air conditioning--and by energy feedstocks, 9 percent of total industrial energy inputs (EPRI, 1978, p. 24).

Before proceeding it is worth renoting the caveat made in chapter 1. The following discussion documents the wide energy differences which exist among countries, among industries, and among industrial processes. Our concern is with one input into the production process--energy. There is little attempt to analyze the total economics of a particular industry or factory. Rather, what this chapter describes is, first, that contrary to the prevalent view of near uniform energy consumption within industries among countries--due to similarity of technology--there is a wide variance in countries' energy input/physical output requirements. And second, there is ample evidence of industrial energy conservation opportunities as seen by intercountry comparisons and intracountry trends over time.

Choice of Industries

To obtain energy intensity measurements we compare "specific energy consumption" ratios in the major energy-consuming industries. This follows the method adopted in chapter 2 whereby industrial energy use was divided by industrial output. For individual industries, however, energy requirements per physical unit of output--usually metric tons--are detailed.

This allows comparisons between countries and over time.[1] For example, a decline in energy use per ton unit of output accords with the general notion of an improvement in the efficiency of energy use.

In the United States the major energy users are primary metals (iron and steel, aluminum, and copper), chemicals, petroleum refining, stone/clay/glass products, which includes cement, paper products, and food products (see table 1-2). All of these except food are considered heavy industries. Since the 1950s the typical development pattern of many LDCs has been to move from an agricultural-based economy to one increasingly based on industrial production--first light industry and then heavy industry[2] (table 4-1). A review of the development plans in the mid-1970s for fourteen developing countries indicates that the movement toward emphasizing heavy industry will continue (UNIDO, 1979, p. 76).

What is significant about this trend of increasing heavy industry production is that these are very energy-intensive as indicated by the United States' 1972 input/output table. The dollar value of energy inputs directly required for each dollar of output (direct coefficients) indicates the relative order of energy-intensive industries. As detailed in table 4-2, the order of energy-intensive industries changes only slightly if to the direct energy coefficients are added indirect energy requirements for

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[1]We do not, however, compare energy intensities for different products intended to provide similar end services--for example, comparisons between steel, cement and bricks; all building materials. While certainly an important topic, cross-product energy intensities are beyond the scope of this short overview on industrial energy demand.

[2]Light manufacturing is defined in terms of the following ISIC divisions and major groups of industry: food, beverages and tobacco (31); textiles, wearing apparel and leather (32); wood and wood products including furniture (33); printing, publishing and allied industries (342); rubber products (355); plastic products (356); and other manufactures (39). Heavy industry consists of the following: paper and paper products (341); industrial chemicals (351); other chemical products (352); petroleum refineries (353); miscellaneous products of petroleum and coal (354); nonmetallic mineral products except products of petroleum and coal (36); basic metals (37); and fabricated metal products, machinery and equipment (38).

Table 4-2. Energy Coefficients For Selected U.S. Industries (dollars)

	Direct energy coefficients[a]	Total energy coefficients[b]
Energy Industries		
Petroleum refining and related industries	.572	1.657
Electric, gas, water and sanitary services	.374	1.322
Coal mining	.155	1.213
Crude petroleum and natural gas	.050	1.073
Extractive Industries		
Chemical and fertilizer mineral mining	.107	.175
Iron and ferroalloy ores mining	.080	.138
Stone and clay mining	.068	.137
Nonferrous metal ores mining	.045	.098
Heavy industries		
Chemicals and selected chemical products	.068	.263
Primary iron and steel manufacturing	.059	.133
Stone and clay products	.048	.119
Paper and allied products, except containers	.046	.120
Glass and glass products	.044	.096
Primary nonferrous metals manufacturing	.031	.109
Miscellaneous machinery, except electrical	.024	.070
Paints and allied products	.022	.129
Other fabricated metal products	.017	.073
Metalworking machinery and equipment	.017	.056
General industrial machinery and equipment	.017	.065
Electrical industrial equipment and apparatus	.015	.060
Light Industries		
Plastic and synthetic materials	.035	.159
Lumber and wood products except containers	.025	.083
Rubber and miscellaneous plastic products	.019	.085
Broad and narrow fabrics, yarns and thread mills	.018	.098
Miscellaneous textile goods	.016	.096
Wood containers	.015	.072
Food and kindred products	.013	.066

Source: Philip Ritz, "The Input-Output Structure of the U.S. Economy, 1972," in Survey of Current Business, U.S. Department of Commerce, vol. 59, no. 2 (February 1979).

[a]Direct input of energy in dollars from the four energy industries--coal mining, crude petroleum and natural gas, petroleum refining and related industry, and electric, gas, water and sanitary services--needed for each dollar of industry output. Derived from Survey's table, "Commodity-by-Industry Direct Requirements."

[b]Energy output in dollars required, directly or indirectly from the four energy industries for each dollar of delivery to final demand of the commodities listed. Derived from Survey's table, "Industry-by-Commodity Total Requirements."

Table 4-1. Shares of Light and Heavy Industry in Total Manufacturing (percent)

	1955		1960		1965		1970		1976	
	Light industry	Heavy industry	Light industry	Heavy industry	Light industry	Heavy industry	Light industry	Heavy industry	Light industry	Heavy industry
World	41.2	58.8	40.7	59.3	37.0	63.0	34.4	65.6	32.3	67.7
Centrally planned economies	49.3	50.7	41.9	58.1	36.0	64.0	33.0	67.0	28.2	71.8
Developed market economies	36.5	63.5	38.0	62.0	35.2	64.8	33.0	67.0	32.4	67.6
Developing countries[a]	67.3	32.7	62.5	37.5	56.8	43.2	52.8	47.2	48.9	51.1
Asia	--	--	69.0	31.0	61.0	38.4	57.9	42.1	55.0	45.0
Latin America	--	--	57.2	42.8	52.3	47.7	47.7	52.3	42.5	57.5

Source: UNIDO, World Industry Since 1960: Progress and Prospects (New York, UN, 1979), p. 66.

[a]Although the totals for developing countries include certain African countries, precise figures for the region of Africa cannot be derived.

each dollar delivery to final demand; that is, total energy required for each subsequent step in the production process. Chemicals and construction products are by far the most energy-intensive manufacturing industries followed by paper and wood products. Textiles, food and machinery are the least energy-intensive. In addition, the energy industries themselves are also quite energy-intensive as are the extractive industries. Given the developing-country shift to these more energy-intensive heavy industries, conservation measures take on added importance.

Since the bulk of industrial energy consumption is accounted for in several key energy-intensive industries, which in turn often consist of only several firms, and since the intent of most developing countries is to expand these industries, a large amount of LDC industrial energy consumption may be explained by reviewing only five industries: iron and steel, cement, pulp and paper, chemicals (fertilizer), and other basic metals (aluminum and copper). However, given the dominant role of food products and textiles in the manufacturing output in most developing countries (UNIDO, 1979, pp. 87-99), these two industries will also be reviewed.

The methodology employed is to look at specific energy consumption per unit output in various countries for which data are available. Even though energy consumption is a function of several factors including technology, product and fuel mix, and other less quantifiable factors as management skills, and though industry-wide specific energy consumption ratios often mask over wide differences among individual plants, these intercountry comparisons, with appropriate discussion, can be quite informative.

Iron and Steel

Despite its capital-intensiveness, a steel industry has been regarded as *sine qua non* for industrialization by many developing countries' governments. Seen as an important indicator of both national economic and military strength, governments have not only encouraged this industry's growth but have become directly involved in the process. As a result of its perceived importance, steel production, already among the major energy uses in many countries and one of the most energy-intensive, will continue to grow rapidly according to known developing countries' industrialization plans (UNIDO, 1978, p. 17). Consequently, energy conservation measures may be important for this industry.

As shown by figure 4-1, most steelmaking energy is initially used in the blast furnace, fully 54 percent. Twenty percent of total energy requirements is for the forming of slabs and blooms and in hot and cold rolling, while only 4 percent is newly introduced in the steelmaking furnaces. However, steel furnaces are the source of 20 percent of all energy losses. In the blast furnace another 15 percent of total energy inputs are lost, largely in the form of heat in slag and cooling water.

Historically, almost all energy used in the blast furnace has been coking fuel for pig iron smelting. And since coke is one of the most expensive fuels in terms of calories, it is not surprising to discover that developed countries with large steel industries have concentrated energy-saving efforts on reducing specific coke consumption. Such efforts have been largely successful. In a recent UN study, for example, it was shown that France had implemented 25 percent coke utilization improvements over the 1967-77 period (ECE, 1980, p. 60). Interestingly, despite the reduction of the coke rate since the 1960s, no appreciable decrease in total ironmaking energy consumption occurred in most developed countries (UNIDO, 1978, p. 169). This is primarily because of the increasing injection of auxiliary fuels in the blast furnace (BF) and the fact that modern blast furnaces produce much less blast furnace gas than did the old furnaces, which then reused this waste gas.

Energy savings have also resulted from technology changes in the steel furnace process. Up until the late 1960s the old Thomas and open-hearth processes were predominant in world steelmaking capacity--70 percent of the total. By 1970, however, there had been a significant shift to the open hearth's successor, the basic oxygen converter furnaces (BOF)--top or bottom blowing. The converter method requires only about 20 percent of the energy needed by the open-hearth method. For those countries which had developed steel industries and then converted over, significant decreases in specific energy consumption have been obtained. Most developing countries, however, with relatively new steel industries never built these old inefficient open-hearth furnaces. Practically none have been built in the world for over ten years.

The specific consumption ratios in table 4-3 comparing energy use per metric ton of steel were compiled from many sources and such data should

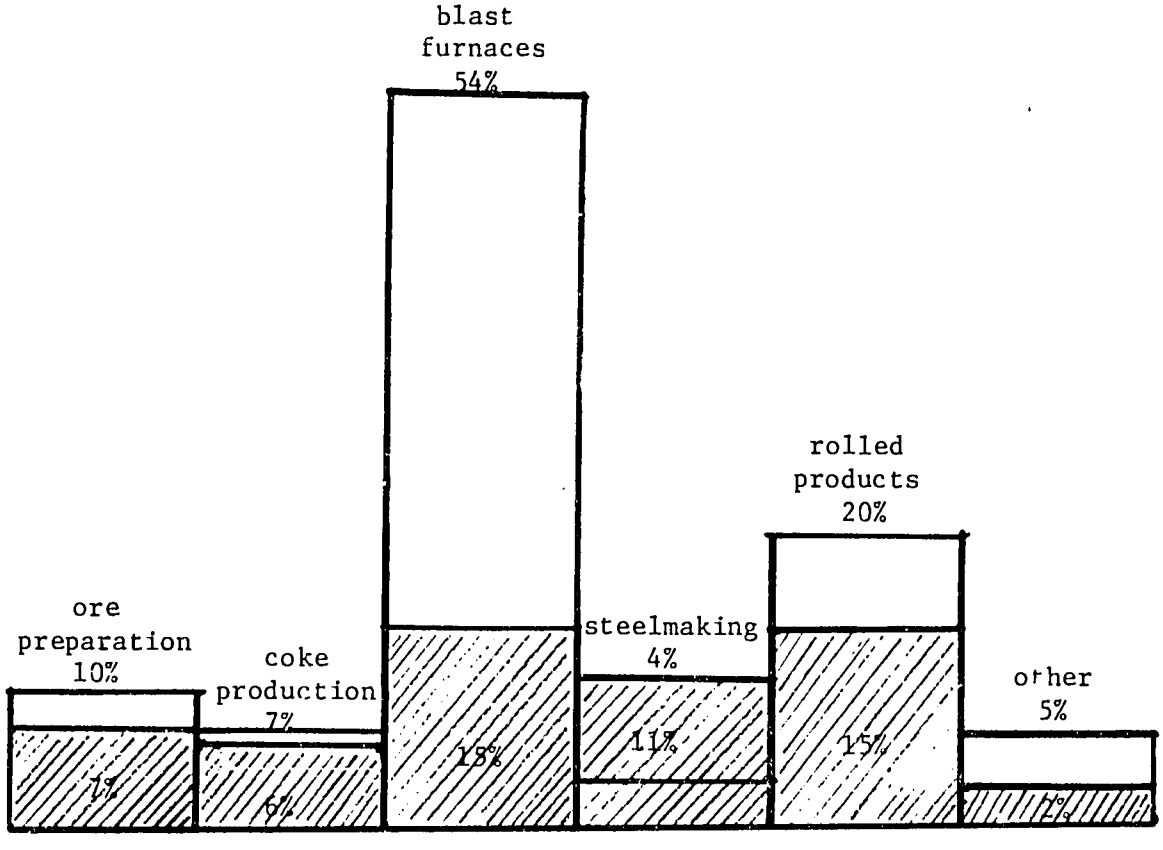

Figure 4-1. Distribution of energy consumption and losses* by stages in the steelmaking process, utilizing pig iron.

Source: Adapted from United Nations, Economic Commission on Europe and Energy Conservation (New York, UN, 1980) p. 58.

*Shaded areas are energy losses.

be viewed with extreme care.[3] Nevertheless there is quite a range in specific energy consumption depending on the country and on steelmaking processes used, varying from lows in Italy and Japan of 3.3-4.3 million kcal/metric ton to extimates of about 17 million kcal in China. Japan's energy efficiency may be attributed to first, its early adoption of continuous casting[4] which saves between 10-15 percent energy per ton output (ECE, 1980, p. 60) over traditional ingot casting in primary mills, and second, to its use of prerolling heating. Italy's apparent energy efficiency is attributed largely to the importance of scrap-fed electric arc furnaces in its overall steel industry which requires the least energy inputs of the steelmaking processes.[5] China, on the other hand, utilizes poor quality ore and coking coal in small, energy-intensive, so-called "backyard" open hearth blast furnaces (Smil, 1978, p. 356). In fact, iron and steel require nearly one-fourth of China's national raw coal consump-

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[3]For example, energy intensities for the United States vary by almost 30 percent depending on whether one uses American Iron and Steel Institute data per ton raw steel (Myers, 1978) or the International Iron and Steel Institute data per ton crude steel. Raw and crude steel theoretically are synonomous. AISI attempts to include all energy used from raw materials to finished steel products. Also IISI data are sometimes cited as per ton rolled steel (ECE, 1980) rather than crude steel despite the fact that there is about a 22 percent difference between the two types due to rolling, cutting and drawing losses. There are problems of measurement resulting from the inclusion/exclusion of coking coal, blast furnace and coke oven gas, different treatments of electricity, the problem of energy sold from the steel mill and simply problems of energy conversion factors.

[4]This process takes molten metal from the final reduction stage and casts it directly into shapes for final use or for subsequent fabrication. The traditional method would be to first cool the steel into ingots which then need to be reheated before being reduced at the primary mill into semi-fabricated blooms, billets and slabs. This reheating process is an important source of added energy consumption.

[5]A drawback to the Basic Oxygen Furnace was that it could accommodate only a limited amount of steel scrap. Therefore electric arc furnaces have been widely adopted and now account for 17 percent of total world steelmaking capacity. The electric arc can use any mixture running from total scrap to total pig iron. If a normal BF/BOF 30:70 pig iron/scrap ratio is used in the electric arc furnace, its specific energy consumption is quite high. However, if 100 percent scrap is used in the electric arc furnace, energy requirements are much lower than for BF/BOF production even after adjusting for electricity transformation losses.

Table 4-3. Specific Energy Consumption Per Metric Ton of Crude Steel (10^4 kcal/metric ton)

Italy[a] (mid-1970s)	334
Japan[b] (1973)	430
United Kingdom[a] (mid-1970s)	478
Germany[b] (1973)	536
United States[a] (mid-1970s)	543
Belgium[b] (1973)	547
Canada[a] (mid-1970s)	555
France[b] (1973)	570
New Zealand[b] (mid-1970s)	739
United States (1970)[c]	749
United States (1973)[c]	695
United States (1976)[c]	723
Bangladesh (1968)[d]	571
Bangladesh (1970)[d]	777
Bangladesh (1973)[d]	501
China, P.R. (1974)[e]	1700
China, P.R. (1978)[f]	389-577
Egypt (1978)[g]	856
Peru (1976)[h]	569
Turkey[a] (mid-1970s)	500
Theoretical minimum[i]	167

[a]International Energy Agency, Energy Conservation in the International Energy Agency 1976 Review (Paris, OECD, 1976) p. 17.

[b]UNIDO, The World Iron and Steel Industry, second ed., UNIDO/ICIS-89 (New York, UN, November 1978) p. 164.

[c]John G. Myers and Leonard Nakamura, Saving Energy in Manufacturing: The Post-Embargo Record (Cambridge, MA, Ballinger, 1978) p. 106. Includes energy from raw materials to finished product stage.

[d]Meta Systems, Inc. and Montreal Engineering Co., Ltd., Bangladesh Energy Study vol. 1, administered by Asian Development Bank under United Nations Development Program (November 1976) p. 2-334.

[e]Vaclav Smil, "China's Energetics: A Systems Analysis," in Chinese Economy Post-Mao (Washington, D.C., Joint Economic Committee, GPO, 1978) p. 356. Coal alone.

[f]Foreign Broadcasting Information Service, Central Intelligence Agency, "PRC National Affairs Publication" 213 (November 1, 1979) p. L13. Coal alone.

[g]Egypt and U.S. Department of Energy, Joint Egypt/United States Report on Egypt/United States Cooperative Energy Assessment vol. 3 (Washington, D.C., GPO, April 1979) p. 25.

[h]Peru and U.S. Department of Energy, Joint Peru/United States Report on Peru/United States Cooperative Energy Assessment vol. 3 (Washington, D.C., U.S. Department of Energy, August 1979) p. 32.

[i]Electric Power Research Institute (EPRI), Efficient Electricity Use 2nd edition, Craig Smith, ed. (New York, EPRI, Pergamon Press) p. 37.

tion, which accounts for 30 percent of its total industrial energy usage. China also has little scrap to use in its furnaces, which would help to reduce primary energy requirements.

The record is mixed in the United States' steel industry because of several conflicting energy use trends. While the use of energy-intensive open-hearth furnaces fell by about 50 percent in the 1970-76 period, replaced by more energy-efficient electric arc and basic oxygen furnaces, and the use of continuous casting tripled (Myers, 1978, p. 114), fuel supply interruptions and environmental controls have kept iron and steel energy requirements from falling steadily. Additionally, capacity underutilization has also been a problem and is reflected in the changing energy intensities. In 1970 and 1976 when there was only 80 percent capacity use, relatively high energy intensity ratios resulted, 7.2-7.5 million kcal/metric ton. When the capacity utilization in 1973 was 98 percent there resulted a 5 percent per metric ton improvement in energy requirements.

Capacity underutilization also explains in part the high energy intensities in Bangladesh's 1967-vintage open-hearth furnaces. These furnaces, which have operated at only 30 percent of full capacity, utilize imported pig iron and scrap. Consequently, coke is excluded from the intensity ratios. Had it been included the 1973 specific energy consumption would probably be near 8 million kcal rather than the listed 5 million kcal. The furnaces and mills utilize petroleum products and electricity although there are plans to switch over to domestically more abundant gas at several of the rerolling mills.

In Peru, even though the specific energy intensity in its single electric arc and three BOF steelmaking plants, which also utilize continuous casting, is comparable to that in many industrial countries, petroleum fuel usage has risen by almost 25 percent between 1972 and 1977. This is largely because petroleum was replacing imported coke in the blast furnace (Peru, 1979, vol. 3, pp. 30-31). In Egypt there also appears to be much greater emphasis on reducing the coke rate--largely by increasing natural gas use--than on pure energy conservation because of the adverse effect of coke imports on its foreign exchange position (Egypt, 1979, vol. 3, p. 22).

These examples of Peru and Egypt lead to a major question concerning steel production in developing countries. While there remains large energy

conservation potential in the recovery of waste gases and low-grade heat for use in boilers for steam production and generation of electric power, long-term energy conservation must focus on the choice of technology. This choice is, in turn, affected by the fact that very little coal, either coking or noncoking, is located in the developing countries. Consequently, in many LDCs, the focus is to not only reduce, but to replace, coke in the ironmaking blast furnace with more readily available fuels. This has been done, for example, by injecting fuel in the tuyeres and hot gas in the stack. As detailed in table 4-4, the specific energy consumption rises substantially with these methods. As a result, while scarce coke is saved, more energy is actually consumed per ton of output.

Another rather energy-intensive process which is gaining popularity in developing countries is the direct reduction method. Many countries have built electric arc furnaces; furnaces which can make steel using from 100 percent pig iron to 100 percent scrap. But since pig iron requires large coke inputs in the blast furnaces and since scrap is generally just as scarce as coke,[6] direct reduction of iron (DRI), pioneered in Mexico, is used instead. Although more energy-intensive, direct reduction allows iron ore to be reduced by low-grade coal or gas reducers to sponge iron, which can then be charged in an electric furnace to be converted into steel. Already operating or being built in Mexico, Argentina, Brazil, India, Korea, and Venezuela, no less than twenty other developing countries have expressed interest in this "mini-plant" direct reduction method (UNIDO, 1978, p. 88).[7] As a consequence, technological improvements in DRI-elec-

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[6]For example, Peru is planning to use more energy-intensive prereduced pellets in future plants in order to replace reliance on imported scrap (Peru, 1979, vol. 3, p. 32).

[7]World capacity of DRI is expected to triple from its present 35 million metric ton level, possibly as soon as by 1990, largely in the developing countries fed by iron oxide raw material mined in Latin America. This projection was made by Jacques E. Astier, president of Societe des Minerais Pereduits at the opening session of the "Direct Reduction-80" Congress held in early August 1980 in Buenos Aires by the Instituto Latino Americano del Fierro y El Acero. Cited in American Metal Market, August 5, 1980.

Table 4-4. Energy Requirements in the Production of Liquid Steel by Various Processes[a] (10^4 kcal/metric ton)

Open hearth furnace	549
Blast furnace/BOF (100% coke)	540
Blast furnace/BOF (coke oven gas injection)	429
Electric arc furnace (100% scrap)	330
Fuel oil injected blast furnace/BOF	485
Fuel oil and reformed gas blast furnace/BOF	601
Electric arc furnace (direct reduction)	522

Source: UNIDO, The World Iron and Steel Industry (New York, UN, 1978) p. 167.

[a]Assumes a 30 percent electricity generating efficiency.

tric arc systems may be the most significant source of future energy conservation potential in the steel industry of developing countries.[8]

Nevertheless, since the more conventional technologies predominate, traditional conservation measures should also be emphasized. Housekeeping items can provide an estimated savings of 3-4 percent of total energy used in steelmaking in the developed countries (UNIDO, 1978, p. 190). Based on sketchy information from countries such as Egypt and Bangladesh, such housekeeping-based savings might be even greater in many developing countries. Also, judging from the record in several industrialized countries, intermediate-term measures such as fuller capacity utilization and increasing electric-furnace and continuous casting capacity, scrap preheating, waste gas/heat recovery, fuel mixing and improvements in soaking pits, annealing and heat-treating facilities could save an additional 5-10 percent of energy consumption per ton of steel output. The post-1973 record in the relatively well-established Indian steel industry, where fuel oil requirements per ton output fell by 20 percent (Desai, 1980, p. 12), would

[8]Interestingly, not only is the BF/BOF route less energy-intensive than the DRI/electric arc process, but one study indicates that for capacities in excess of one million tons the capital cost per ton BF/BOF capacity is also less than for the combined DRI/electric arc facilities (UNIDO, 1978, p. 95).

seem to confirm such potentialities. Detailed estimates for Egypt show similar conservation potential (Egypt, 1979, vol. 3, p. 28) although increased gas use to replace coke inputs may counteract such energy savings.

Cement

Like iron and steel production, cement production is rather energy-intensive. Also as with the steel output, cement production will generally rise with overall industrial growth resulting from its important role in construction and development activities including the building of a nation's infrastructure, roads, bridges and buildings. Additionally, cement is a relatively easy product to produce and as such most developing countries already have in place some cement-producing capacity.

A study completed in the mid-1970s (Gordian, 1976) detailed that energy consumption in the cement industry is a function of process used, raw materials, age and capacity of the kilns, operator experience and steadiness of operation. Of these, the most important factor is the process of production. Representative fossil fuel requirements per metric ton cement show that the so-called wet process (1.3 million kcal) is almost 40 percent more energy-intensive than the dry process operating in conjunction with suspension preheating kilns (.8 million kcal). The study also reported that the larger the kiln the greater the energy efficiency.

The production of "pure" portland cement is dominant in most countries and is produced through a four-step process. First, the raw material compounds containing lime, silica and alumina must be obtained. Significant energy savings might be obtained through increased production of blended slag cement--portland mixed with a natural filler or industrial by-products such as fly ash from pulverized coal-fired power plants and finely ground blast furnace slag. For example, blast furnace slag from the Egyptian Melwan steel plant is quenched, granulated and then sent to a nearby cement works (Egypt, 1979, vol. 3, p. 3-23). Exact energy savings are unknown but estimates in France indicate a potential 20 percent overall savings (Gordian, 1976, p. 5) on a ton-for-ton cement equivalence.

Second, the raw materials must be crushed to fine particle size and, if containing high water content, made into a slurry (wet process) or dried immediately by hot gases from the kiln (dry process). Third, the

raw material is burned in a rotary kiln. If the wet process is used, relatively more energy is needed to evaporate the water which was added in the blending process. The modern kilns will often use a preheater system by which the hot waste gases from the kiln and from the rough-textured lumps or pellets (clinker) which leave the kiln are reused to preheat incoming raw materials and combustion air. About 80 percent of the energy used in the cement manufacturing plant is in the kiln. Finally, the clinker is mixed with gypsum (controls setting time when mixed with water) and ground into a fine powder.

Table 4-5 presents specific energy consumption ratios for several countries. In all cases the dry process is notably less energy-intensive than the wet process. For this reason developing countries which have a relatively new cement industry (e.g., Peru) or are planning capacity additions (e.g., Egypt) generally opt for the dry process. An exception, for example, is in Haiti where in 1975 a 300,000 metric ton capacity wet-process kiln was installed apparently due to the desire to avoid the higher capital costs of a dry-process investment (Cecelski, 1980, p. 58).

Among the industrialized countries, Germany and Italy have the lowest energy intensities (.82-.89 million kcal per metric ton output) largely because dry and semidry processes dominate the countries' industries, 92 and 86 percent respectively. By contrast about 70 percent of 1974 production in the United Kingdom (1.3 million kcal) and 60 percent in the United States (1.5 million kcal) was by the older, less energy-efficient wet process (Gordian, 1976, p. 8). Almost all of the German capacity is post-1955 vintage, whereas 11 percent of the U.S. capacity existed prior to 1935.

In the United States energy savings in both the wet and dry processes have taken place since 1973 primarily due to replacement of old plants and equipment. The addition of energy-saving devices such as preheaters and better insulation contributed to the savings (Myers, 1978, p. 101). Some improvement also resulted by changing to dry from wet processes. Air pollution controls, however, counteracted much of the total conservation efforts.

There is some evidence that choice of fuel influences energy efficiency although there are no clear trends. India's kilns, for example, which

Table 4-5. Specific Energy Consumption per Metric Ton of Cement

	Dry process		Wet process		Overall	
	Kiln fuel[a]	Electricity[b]	Kiln fuel[a]	Electricity[b]	Kiln fuel[a]	Electricity[b]
Germany, F.R.[c] (1974)	74-90	N.A.	120-140	N.A.	82.3	118
Italy[c] (1974)	99.0	127	148.5	112	89.0	123
Japan[d] (mid-1970s)					119.6	*
Netherlands[c] (1974)	90.0	N.A.	148.6	N.A.	129.3	N.A.
United Kingdom[c] (1974)	88.6	127	159.6	99	129.6	106
Sweden[d] (mid-1970s)					139.7	*
United States[c] (1974)	135.8	163	169.9	144	149.0	152
United States[e] (1970)	196.8	*	219.4	*	210.4	*
(1973)	187.1	*	222.1	*	207.6	*
(1976)	185.3	*	217.1	*	202.9	*
Turkey[d] (mid-1970s)	98.0	*	139.0	*	N.A.	N.A.
Peru[f] (1976)	90-112	115-137			111.1	137
Kenya[g] (1975)					151.2	90
(1977)					133.6	90
Egypt[h] (1975)			162.0	105	162.0	105
India[i] (1970)					188.1	117
(1977)					169.7	122
Bangladesh[j] (1973)			169.2	154	169.2	154
Dominican Republic[k] (1978)	99.4	N.A.	186.1	N.A.	N.A.	N.A.
Haiti[k] (1978)			199.0	N.A.	199.0	N.A.
Best modern technology[l]					85.0	110-120
Theoretical minimum[m]					9.6	*

Note: N.A. = Not available.

* = Electricity included in kiln fuel.

[a] 10^4 kcal/metric ton.

[b] KWh/metric ton.

[c] Gordian Associates, Inc., Industrial International Data Base: The Cement Industry, prepared for the Committee on the Challenges of Modern Society, NATO (New York, ERDA, Technical Information Center, 1976) p. 38. Dry Process includes suspension preheating. Both wet and dry processes' kiln fuel use is actually for tons clinker instead of for tons cement. Overall kiln fuel use in 10^4 kcal/metric ton clinker is: U.S., 156.9; Germany, 97.7; Italy, 105.8; and U.K., 137.9.

[d] International Energy Agency, Energy Conservation in the International Energy Agency 1976 Review (Paris, OECD, 1976) p. 18. Electricity included in kiln fuel--100 kwh = 8.6 kcal.

[e] John G. Myers and Leonard Nakamura, Saving Energy in Manufacturing: The Post-Embargo Record (Cambridge, MA, Ballinger, 1978) p. 99. Electricity included in kiln fuel.

[f] Peru and U.S. Department of Energy, Joint Peru/United States Report on Peru/United States Cooperative Energy Assessment, vol. 3 (Washington, D.C., U.S. DOE, August 1979) p. 40.

[g] Lee Schipper, "Energy Demand and Conservation in Kenya." Paper presented at the Electric Power Research Institute Workshop on Energy and the Developing Nations, Hoover Institution, Stanford University, March 1980. Data are for a single plant.

[h] Egypt and U.S. Department of Energy, Joint Egypt/United States Report on Egypt/United States Cooperative Energy Assessment, vol. 3 (Washington, D.C., GPO, April 1979) p. 49.

[i] Ashok V. Desai, "Inter-Fuel Substitution in the Indian Economy" (Draft, Washington, D.C., Resources for the Future, 1980) p. 14.

[j] Meta Systems, Inc., and Montreal Engineering Co. Ltd., Bangladesh Energy Study, Appendix I, vol. 1, administered by Asian Development Bank under United Nations Development Program (November 1976) p. 2-325. Data are for a single plant.

[k] Elizabeth Cecelski, "Prospect for Energy Conservation in a Low Income Developing Country: The Case of Haiti." Paper prepared for Oak Ridge Associated University and U.S. Agency for International Development (April 1980) p. 59.

[l] Philip F. Palmedo and Pamela Baldwin, The Contribution of Renewable Resources and Energy Conservation as Alternatives to Imported Oil in Developing Countries (Port Jefferson, NY, Energy/Development International, February 1980) p. 62.

[m] Electric Power Research Institute, Efficient Electricity Use, 2nd edition, Craig Smith, ed. (New York, EPRI, Pergamon Press) p. 37. Electricity included in kiln fuel.

use primarily coal for their kiln fuel have higher energy intensities than most oil- or gas-burning kilns. At the same time, however, India experienced a 9 percent energy-intensity improvement over the 1970-77 period despite coal use rising from 90 to 94 percent of total energy inputs. It may be that rising capacity utilization explains part of the improved fuel efficiency (Desai, 1980, p. 14).

Similarly, the record is not clear as to the efficiency of natural gas usage which varies greatly in two countries utilizing 100 percent gas as their kiln fuel. In the Netherlands it requires only 1.3 million kcal/metric ton cement while in Bangladesh the specific consumption is among the highest at about 1.7 million kcal/metric ton. Future facilities in Bangladesh, however, will incorporate the latest energy-saving technology --dry process, raw material drying with waste heat prior to grinding, improved insulation, oxygen enrichment and increased kiln rotation speeds. These measures should help lowe its industry-wide cement specific energy consumption ratio.

Egypt is another country whose operating management has shown an awareness of standard energy conservation measures, but given financial constraints, has not been able to convert old kilns to new processes. Its cement industry consists of four companies using entirely wet-process kilns, some dating back to the 1930s. This partially explains Egypt's cement industry's high overall consumption intensity. Nevertheless, its specific consumption is still comparable to the wet processes used in the industrial countries. Peru's five government-owned companies, which all use the dry process, are also operating close to international standards.

As we have seen, kiln fuel consumption per metric ton output varies widely throughout the world cement industry. Electricity consumption, however, falls within a relatively narrow range, between 90 and 150 kWh per metric ton (about .1 million kcal/metric ton).

As detailed, energy conservation potential in the cement industry largely depends on the choice of kiln fuel and type of process--preferably the dry process in conjunction with waste heat recovery, suspension preheating, and particle size control. When possible the production of blended slag cement should be encouraged over portland cement. Comparisons between countries, for example, the Netherlands and Bangladesh, indicate that housekeeping measures might contribute significantly to energy savings in at least some developing countries. Studies in Kenya (Schipper, et. al 1980, p. 3) and Haiti (Cecelski, 1980, p. 58) indicate that substantial energy could be saved by simply plugging obvious leaks. An estimated 5 percent of total energy used in one of the Haitian kilns could be saved by repairing a seal leak, but this, it was noted, would require shutting down the kiln and therefore had been postponed.

Pulp and Paper

Energy data for the paper industry are not easily obtained despite it being among the fastest growing industries in the LDCs during the 1960-74 period, averaging about 8 percent in each developing region of Asia, Africa and Latin America (UNIDO, 1980, p. 68). Some of the data inadequacies derive from the structure of the industry in which there are pulp mills, paper mills and integrated pulp/paper mills, each with varying energy requirements. Other data constraints result from the large internal generation of energy and the use of cogeneration processes.

The forest products sector is divided into two subsectors. The first is the pulp and paper sector which manufactures pulp, paper and paperboard. The second is the mechanical wood processing sector which includes the manufacturing of sawnwood and wood-based panels such as plywood, particle board and fiberboard. Data for Europe and the United States indicate that both absolute energy consumption and specific energy consumption for the pulp and paper sector are much greater than for the mechanical wood-processing sector (ECE, 1980, pp. 35-37). For most of these countries specific energy consumption in the mechanical wood-processing industry has

risen since the mid-1960s primarily as a result of the increased share of wood-based panels at the expense of less energy-intensive sawnwood.[9]

Much more energy is required per unit output in the pulp and paper industry; energy which is needed to break down the wood raw materials into fibers suitable for paper and paperboard manufacturing. Energy fuels are used to dry the products and to generate process steam through boilers, whereas electricity is mainly consumed in electric motors to drive refiners, fans, pumps, etc. Consequently, direct substitution between fuels and electricity is usually not feasible. Energy fuels are also used for lime reburning in chemical pulp mills.

The industry derives a substantial amount of its energy use from self-generated fuels, particularly from spent liquors[10] which, in turn, have been closely linked to the growth of chemical Kraft pulping over conventional mechanical (i.e., grinding) pulping. The spent liquor from the chemical pulping process is pumped into the recovery boiler where the dissolved wood substances it contains are burnt together with the chemicals. The steam generated in the recovery boiler is used for electricity generation and as heat for cooking, bleaching and drying purposes. Chemical pulp mills reach a high degree of self-sufficiency with regard to fuel

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[9] Data for Sweden in 1972 shows that the average specific energy consumption ratios vary widely for different wood products (United Nations, 1980, p. 35):

	Thermal energy (10^4 kcal/m^3 product)	Electricity (kWh/m^3 product)
Sawmills	8.7	39
Veneer and plywood mills	64.8	318
Particle board mills	34.5	356
Fiberboard mills	156.6	476

[10] Lignin and hemi-cellulose separated from the cellulose during chemical pulping. In 1976 the American Paper Institute published U.S. data indicating that 41 percent of the 2332.5 trillion Btus consumed in the paper industry were from self-generated and waste fuels of which about 80 percent were from spent liquors. (cited in Myers, 1978, p. 58).

consumption and also to the share of electric power generated from internal sources. However, the pulping liquors are also less efficient sources of energy than conventional fuels and, with their increased use, have resulted in higher specific energy consumption ratios. For example, even in the most modern plants there is a 40 percent loss of the Btu content in converting wastes to steam.

Contrary to sulphate pulp mills, pulp yield in mechanical pulp plants is almost 100 percent so that internal sources for heat and power generation are limited. Mechanical pulp mills' electricity consumption, which is two or three times as high as in chemical pulping, is largely for chip refining with most of the energy input transformed into uneconomic low pressure steam.

Similarly, a nonintegrated paper mill has no internal sources for energy so that the possibilities of cutting down on specific energy input are less promising than in chemical pulp mills unless a new energy-minimizing technology emerges. Evidence points to the efficiency of an integrated pulp-paper mill where a substantial share of its heat demand can be obtained from the available surplus of steam generated in the recovery and bark boilers (ECE, 1980, p. 31). Examples of various Swedish mills with their specific energy consumption and percentage contribution of internally generated heat and power are presented in table 4-6. While a nonintegrated mechanical pulp mill and nonintegrated paper mill uses less energy than a nonintegrated chemical pulp mill, an integrated pulp-paper mill uses less energy than is collectively required in nonintegrated pulp and paper mills. An integrated pulp-paper mill also enables the manufacturer to employ internal energy sources for up to 60 percent of total energy requirements.

Data available for most of the developed countries published in a 1980 report by the U.N. Economic Commission for Europe are only as recent as 1972 (ECE, 1980, p. 36). Specific energy consumption for the pulp and paper industry available from the International Energy Agency is also for 1972 and apparently includes only purchased fuels. However, the data presented in table 4-7 do indicate several points. United States data show that the use of internally generated waste fuels can provide a significant proportion of total energy requirements. In fact, the theoretical minimum indicates that total energy needs may be internally met. Indicative

Table 4-6. Specific Energy Consumption and Percentage Contribution[a] of Internally Generated Energy in Swedish Mills, 1973 (10^4 kcal/metric ton pulp, 90 percent dry)

	Steam	Electricity
Nonintegrated chemical pulp mill	313-419 (50-80)	55-83 (40-60)
Nonintegrated mechanical pulp mill	72 (0-10)	146 (0)
Nonintegrated paper mill	207-289 (0)	60-112 (0)
Integrated pulp-paper mill	265-434 (30-75)	86-181 (20-30)

Source: Derived from United Nations, The European Commission for Europe and Energy Conservation, Recent Experience and Prospects, E/ECE/985 (New York, UN, 1980), p. 31.

[a]Figures in parentheses are percentages of internally generated energy in each process.

of this potential is one new mill in the United States which reportedly meets 80 percent of its energy needs from pulping liquors, bark and wood wastes (Office of Industrial Programs, 1979, p. 13).

Bangladeshi data for its two largest paper mills indicate that its specific energy consumption may be larger than are many other countries'. Part of this is directly related to capacity underutilization. In 1969 capacity was being used at near 80 percent and about 12.4 million kcal/metric ton was required. Following the 1970-72 war years capacity utilization was only 60 percent resulting in a 30 percent energy efficiency decline. The newsprint plant uses a mechanical pulping process which requires a relatively large amount of electricity. Most of its electricity is self-generated. Writing paper production is through a sulphate process utilizing relatively more steam. It is unknown how much of the energy use is due to inefficient waste recycling (Bangladesh, 1976, vol. 1, pp. 2-303 - 2-306).

Table 4-7. Specific Energy Consumption Per Metric Ton of Pulp, Paper and Board
(10^4 kcal/metric ton)

United States[a] (1976)	
purchased fuels	570
total fuels	970
Canada,[b] total fuels (1975)	755
Sweden[c] (1973)	756
Kenya[c] (1977)	1285
Bangladesh[d] (1965)	
newsprint	1355
writing paper	1464
Bangladesh[d] (1969)	
newsprint	1204
writing paper	1264
Bangladesh[d] (1973)	
newsprint	1566
writing paper	1722
Best modern technology[e]	659
Theoretical minimum[e]	0 - 2

[a]John G. Myers and Leonard Nakamura, Saving Energy in Manufacturing: The Post-Embargo Record (Cambridge, MA, Ballinger, 1978) pp. 58-59.

[b]Economic Commission for Europe, The Economic Commission for Europe and Energy Conservation: Recent Experience and Prospects E/ECE/985 (New York, United Nations, 1980) p. 36.

[c]Lee Schipper and Oyuko Mbeche, "Energy Demand and Conservation in Kenya." Paper presented at Conference on Energy and Environment in East Africa, Nairobi, Kenya, May 5-11, 1979, table 2. Estimates apparently include all fuel sources including cogeneration facilities.

[d]Meta Systems Inc. and Montreal Engineering Co., Ltd., Bangladesh Energy Study Appendix I, vol. I administered by Asian Development Bank under United Nations Development Program (November 1976) p. 2-305. Apparently includes internal fuel sources.

[e]Electric Power Research Institute, Efficient Electricity Use, 2nd edition, Craig Smith, ed. (New York, EPRI, Pergamon Press, 1978) p. 37.

Although the data do not provide a description of product mix, Kenya's specific consumption does not compare favorably to Sweden's. However, like Sweden, Kenya utilizes a cogeneration process, i.e., combined steam and electricity generation from the same fuel source. In fact, Pan African Paper Mills is the only nonagricultural Kenyan firm to do so (Schipper, 1979, p. 11). This reflects a recognition that the forest sector provides more opportunity than do most other sectors to be completely self-sufficient for all of its heat and power requirements. Part of Sweden's favorable specific energy consumption might be explained by its large use of integrated chemical pulp and paper mills--a development which could offer significant energy savings elsewhere.

Chemicals and Petrochemicals--Fertilizers

The chemical industry is one of the most energy-intensive industries and, in the United States, is also the second major end user of energy following primary metals. While the reasons are complex and manifold, a major explanation lies with the dual role of energy in the chemical industry as both a feedstock and a fuel. On a worldwide scale the chemicals industry consumes three-fifths of its energy for energy purposes and two-fifths as raw material (ECE, 1980, p. 45). The importance of the chemicals industry to total energy demand is of special significance because chemical energy consumption since the 1950s has been characterized by the predominance of oil and a rapid increase in natural gas use.

Chemicals and petrochemicals are of extreme importance in many developing countries' overall industrial energy demand. For example, in Bangladesh, chemicals (i.e., fertilizers) are the largest consumers of energy (Bangladesh, 1976, vol. 1, p. 2-125), are third in importance in Egypt following metals and building materials (Egypt, 1979, vol. 1, p. C-36), and in India utilize more scarce fuel oil than does any other industry (Desai, 1980, p. 12). Between 1960-74, industrial chemicals' output in developing countries has grown at the phenomenal rate of 12.3 percent (UNIDO, 1980, p. 68). Many LDC development plans project that the chemicals industries will continue their rapid growth over the next few years.

Due to the nature of the technology, four stages of production result in the high fuel energy-intensities of chemicals: separation technology, chemical conversion, utilization of low temperature heat, and reduction of inert materials (Burch, 1979). The specific processes and their requisite energy impacts vary from chemical to chemical and indeed over time. Yet, each new chemical and process tends to undergo a long history of industrial development, beginning from an early stage of relatively inefficient production methods, usually batch processing, and eventually reaching highly efficient large-scale continuous production if it finds or makes a large enough market. This dynamism has enabled the industry to save energy at a rapid pace (Myers, 1980, p. 62). These dual aspects--high energy variability among chemicals and declining specific energy consumption over time--are well documented in table 4-8 which gives the energy/output ratios of fifteen representative organic chemicals in the United States. All but one of the chemicals experienced a decline in specific energy consumption during the 1967-76 period. Their energy-intensiveness varies from a high of almost 23,000 Btu/pound to one chemical, formaldehyde, actually being a net energy producer.

Studies by the United Nations indicate that greatest conservation savings have occurred and will continue to occur as a result of housekeeping measures--5 to 10 percent--and technological improvements inside the production plant, which from 1970-76 resulted in one-half of all energy savings--2 to 24 percent--depending on product and country (ECE, 1980, pp. 47-49). Other potential savings exist in waste heat recovery, utilization of gas-to-gas and shell-and-tube exchanges to recover heat in the flue gases, preheating combustion air, better insulation and improvements in furnace efficiencies.

Chemical energy requirements in many developing countries are primarily for fertilizer manufacturing. For example, fertilizer production requires about 50 percent of total energy inputs in the Mexican petrochemical industry (Bazan, 1979, p. 52) and 73 percent of the Peruvian chemical energy demand (Peru, 1979, vol.3, p. 1). This is not entirely unexpected given the agricultural base of developing country economies in general and their productivity improvements resulting from the 1960s-70s chemical-based "green revolution" in particular. In fact, fertilizers

Table 4-8. Energy-Output Ratios by Chemical for Selected Years in the United States
(1,000 Btu per pound)

	1967	1971	1974	1975	1976
Acetic acid	12.8	11.3	10.2	9.9	9.5
Acetone	3.4	3.0	2.6	2.5	2.4
Acrylonitrile	4.3	3.0	2.0	1.7	1.4
Adipic acid	14.5	13.4	12.6	12.3	12.1
Carbon disulfide	3.0	2.7	2.5	2.4	2.3
Ethyl alcohol	5.4	5.3	5.2	5.1	5.1
Ethyl chloride	2.2	2.1	2.1	2.1	2.1
Ethylene glycol	7.0	5.4	4.1	3.7	3.3
Formaldehyde	2.0	1.1	0.4	0.15	-0.1
Hexamethylene diamine	34.0	29.0	25.2	23.9	22.7
Isopropyl alcohol	6.0	5.5	5.2	5.1	4.9
Methyl alcohol	7.0	6.8	6.7	6.7	6.7
Perchloroethylene	2.8	2.7	2.6	2.6	2.6
Trichloroethylene	2.0	3.5	4.7	5.1	5.5
Urea	4.0	3.4	2.9	2.8	2.6

Source: John G. Myers and L. Nakamura, Saving Energy in Manufacturing: The Post-Embargo Record (Cambridge, MA, Ballinger, 1978), p. 139.

have been among the top six growth industries in the developing countries since the mid-1960s (UNIDO, 1979, p. 110).

There are two major types of fertilizers--phosphatic nutrients and nitrogeneous nutrients. Nitrogen (N) is the more important and by far the most energy-intensive element in fertilizers. Normally it is applied as a "straight" N fertilizer, usually as ammonia nitrate (34.5% N), but also as ammonium sulphate (21% N), urea (46.6% N) or liquid ammonia (82.4% N) (Leach, 1976, p. 73).

The data in table 4-9 indicate a wide variation in specific energy consumption for fertilizers both by type of nitrogen product and by type of synthesizing process. Generally, using natural gas as a feedstock is

Table 4-9. Specific Energy Consumption Per Metric Ton of Fertilizer (10^4 kcal/metric ton)

	10^4 kcal	Product and fuel process
United States[a] (1973)	1132	ammonia
United Kingdom[b] (early 1970s)	50	phosphate
	619	ammonium nitrate, natural gas
	922	urea, natural gas
	1223	liquid ammonia, natural gas
Czechoslovakia[c] (1970-76)	860-1123	ammonia, natural gas
	1911	ammonia, coal
China, P.R. (1974)[d]	2300-3100	liquid ammonia, coal/coke
(1979)[e]	1100-4670	liquid ammonia, coal/coke
Egypt[f] (1975)	119	phosphate
	645	ammonium nitrate, natural gas
	1625	ammonium nitrate, electrolysis
Peru[g] (1976)	717	ammonium nitrate electrolysis
	1040	urea, natural gas

Ammonia production[h] by:	Process energy	Fuel stock	Total
High-methane natural gas			812
Naphtha-steam reforming	382	597	979
Fuel-oil-partial oxidation	215	764	979
Water electrolysis	1218	-	1218

[a]Earl Hayes, "Energy Implications of Materials Processing," Science, vol. 191, no. 4228, February 20, 1976, p. 664.

[b]Gerald Leach, Energy and Food Production (London, IPC Business Press, 1976) pp. 72 and 74. Includes energy for packaging, transport and capital overhead. These energy costs are well below 10 percent of the totals.

[c]Economic Commission for Europe, The Economic Commission for Europe and Energy Conservation: Recent Experience and Prospects E/ECE/985 (New York, United Nations, 1980) p. 47.

[d]Vaclav Smil, "China's Energetics: A Systems Analysis," in Chinese Economy Post-Mao (Washington, D.C., Joint Economic Committee, GPO, 1978) p. 357.

[e]Foreign Broadcasting Information Service, Central Intelligence Agency, "PRC National Affairs Publication" 213 (November 1, 1979) p. L13.

[f]Egypt and U.S. Department of Energy, Joint Egypt/United States Report on Egypt/United States Cooperative Energy Assessment vol. 3 (Washington, D.C., GPO, April 1979) p. 77.

[g]Peru and U.S. Department of Energy, Joint Peru/United States Report on Peru/United States Cooperative Energy Assessment vol. 3 (Washington, D.C., U.S. DOE, August 1979) p. 68.

[h]Egypt and U.S. Department of Energy, Joint Egypt/United States Report on Egypt/United States Cooperative Energy Assessment vol. 3 (Washington, D.C., GPO, April 1979) pp. 79 and 81.

the most energy-efficient means of producing ammonia. The United Kingdom's ratios for each product, based upon the utilization of natural gas, are lower than those of most other countries. In Peru, efficiency of production for both ammonium nitrate (NH_4NO_3) from electrolysis and urea using natural gas as a feedstock is less than for similar production processes in the United Kingdom. Egypt's NH_4NO_3 production efficiency is comparable to the United Kingdom's when gas is the feedstock and is believed to be performing above normal world standards. However, production is over twice as energy-intensive in its Kima electrolytic fertilizer plant. This process uses hydroelectric power in electrolytic cells to produce one of the two feedstocks, hydrogen, for ammonia production. The other feedstock, nitrogen, is produced from an air separation plant.

Although the range varies widely, China's specific consumption for ammonia production is quite high due mainly to the small capacity of its plant and to the utilization of coal, coke and coke oven gas for its nitrogen synthesis (Smil, 1978, p. 357). Indications of the energy inefficiencies of coal as a feedstock for nitrogen is also seen in Czechoslovakia's energy use data. In the 1970-76 period, utilizing coal resulted in over twice the energy per ton ammonia output than did production from natural gas. The efficiency of natural gas in fertilizer production is in fact well appreciated in most countries. Gas that previously was either flared or used in other manufacturing sectors is now often used for ammonia production. Colombia, for example, is currently engaged in a program to replace liquid fuels by gas in its fertilizer industry (Prada, 1979, p. 30).

Bangladesh's two fertilizer plants also utilize natural gas for generation of steam and electricity and for its urea feedstock making the fertilizer industry the second largest user of energy in Bangladesh (Bangladesh, 1976, vol. 1, p. 2-313). Its efficiency of use, however, has generally been poor due to the smallness of its plants and their bad state of repair.

Until recently, Mexico's fertilizer industry had been based on steam reforming of naphtha. Newly discovered abundant reserves of gas should change this. Given little natural gas in India, most of its 1960s-built urea plants also relied on naphthas as their feedstock. However, due to supply constraints of both petroleum fuels and gas, two coal-based urea

plants are also being built which will be more energy-intensive and, due to technology which requires the gasification of coal, more capital-costly than gas- or oil-based plants. Future plants are expected to be based on gas obtained from Bombay High (Desai, 1979, pp. 30-33).

The bulk of energy savings in the chemical industry has resulted first from housekeeping measures and second from the "natural" stages of technological progress of production--small energy-inefficient production followed by large-scale continuous energy-efficient production. In developing countries fertilizer production has been by far the major chemical produced. The choice of feedstock is most important when considering specific energy consumption: natural gas is the preferred fuel source. If gas is not available, developing countries would best utilize naphthas or fuel oils over coal. Water electrolysis appears to be the least energy-efficient.

Where industries are well established and fundamental changes unlikely, for example in Egypt, normal housekeeping measures may result in significant energy savings (Egypt, 1979, vol. 3, pp. 72-83). Also, where agriculturally feasible, phosphatic fertilizers, which are only one-tenth to one-fifth as energy-intensive as nitrogeneous fertilizers, should be promoted.

Basic Metals--Aluminum

Despite the important role accorded the metals industries in many developing countries, little data appear to be available on energy requirements starting from the point of minerals extraction up to the fabricating stage. Yet, table 4-2 detailed the extreme energy intensiveness of the extractive industries. While the refined/fabricated metal products require much less energy on a dollar per dollar basis, there are exceptions. Aluminum production, for example, is quite energy-intensive. Compare, for example, Egypt's specific energy consumption of 21.2 million kcal/metric ton of aluminum (Egypt, 1979, vol. 3, p. 41), to Peru's 8.8 million kcal/average metric ton of lead, zinc and copper--4.1 million kcal/metric ton for conversion of ore to refined copper alone (Peru, 1979, vol. 3, pp. 13-14). For those developing countries with substantial minerals extraction/

metals production industries, the implication of such large specific energy consumption is quite significant.[11]

Table 4-10 provides the specific consumption requirements per metric ton of aluminum in several countries. The production of aluminum requires energy for bauxite mining, for refining bauxite to alumina and for smelting alumina to aluminum. The major requirement in aluminum production is electricity for aluminum smelting. This has resulted in several developing countries, rich in hydropower or petroleum, but poor in bauxite resources, building aluminum production facilities and importing the bauxite. Egypt's hydropowered Aswan Dam plant is one such example. Beginning production in 1976, this plant's specific energy consumption appears to be on the high side. It has been suggested that a reduction in its anode current density would result in 6.5 percent energy savings (Egypt, 1979, vol. 3, pp. 40-41). Pot insulation might provide an additional 1 percent savings.

It would appear that little can be done to lower the energy used in reducing alumina to aluminum ingot or billet in an existing smelting facility. Savings can be achieved by using more scrap and by the introduction of continuous casting, but once a potline is installed, it cannot be altered without extensive rebuilding, which is seldom economical. Significant savings (3 percent) were obtained in the United States during the 1974-77 period mainly as a result of shutting down the least efficient facilities and of a substantial rise in the recycling of aluminum scrap. Producing a ton of aluminum from scrap requires only 5 percent of the energy needed to produce a ton of aluminum from bauxite (ECE, 1976, p. 68).

As has been the case in so many of the industries reviewed, the major energy savings in the aluminum industry should result from expanding or building new facilities; in this case aluminum smelting facilities. Efficiency improvements of around 40 percent have been proven possible by

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[11] For example, in Jamaica the bauxite industry consumed about 50 percent of total petroleum products in 1973. Following the oil price rise, the industry's energy demand declined by 40 percent over the 1974-76 period as did indeed alumina production. This helped prompt a series of energy end-use surveys, including of the bauxite sector (Byer, 1979).

electrochemical processes, such as the new Alcoa process, or new chemical techniques such as the Tosh process (ECE, 1976, p. 68).

Table 4-10. Specific Energy Consumption per Metric Ton of Aluminum (10^4 kcal/metric ton)

United States[a]	947
Japan[a]	1385
Germany[a]	1481-1503
Norway[a]	1591
Sweden[a]	1648
United Kingdom[a]	2107
New Zealand[a]	2165
Egypt[b]	2120
Spain[a]	2800

[a]International Energy Agency, Energy Conservation in the International Energy Agency 1976 Review (Paris, OECD, 1976) p. 18. For the United States, excludes bauxite mining. For Norway and the United Kingdom, data are for electricity only. Data are for mid-1970s.

[b]Egypt and U.S. Department of Energy, Joint Egypt/United States Report on Egypt/United States Cooperative Energy Assessment vol. 3 (Washington, D.C., GPO, April 1979) p. 41. All bauxite ores are imported. Datum is for 1978.

Textiles

Unlike the industries already reviewed, the textile industry is not a major energy consumer in the United States--less than 3 percent of total industrial energy consumption. Nor does its energy requirements per dollar value of output rank anywhere near the most energy-intensive industries (table 4-2). Yet in many developing countries textiles consistently rank among the top industries in percentage contribution to total manufacturing output (UNIDO, 1979, pp. 87-99). In addition, we have already seen (table

2-6) that the electricity intensity of the textile industry has been increasing since the 1960s. Data presented in appendix B (table B-1) indicate that textiles are major electricity consumers in an absolute sense as well. What then might be the energy conservation potential of this largely overlooked industry?

In the United States it would appear to be quite substantial. The textile industry's 1980 net energy reduction target of 22 percent was second only to the goal established by fabricated metal products. By the end of 1978 the textile industry was only 1 percentage point shy of its target. The main energy efficiency improvements were attributed to such activities as minimizing drying requirements, increasing plant and machinery insulation, combining or eliminating processing steps, reclaiming waste heat, improving boiler efficiency, and reducing processing temperatures. Textile manufacturers are expected to continue focusing their attention on more energy-efficient housekeeping and maintenance measures (Office of Industrial Programs, 1979, pp. 10-11).

According to estimates made in one recent study on the U.S. textile industry (Georgia, 1979), conservation potential in the wet processing segment of the industry (dyeing, bleaching, finishing, drying, etc.) remains at 31 percent of its total energy consumption on top of the improvements already obtained. Specifically, the greatest energy saving potential exists in improvements in the atmospheric dye becks (kettles) common to the industry and in drying operations.[12] Since wet processing operations consume 60 percent of the industry's total energy requirements, this equates to 19 percent of total textile energy demand. Wet processing operations

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[12]The atmospheric dyeing operation is fairly simple. Fabric to be dyed is placed in a large vessel containing water, to which the dye and any supplemental chemicals are added. Generally, the dyes require temperatures near the boiling point of water for fixation. Water is normally heated by direct injection (sparging) of steam into the vessel. Lower specific consumption in drying may be obtained by reducing the liquor ratio, eliminating exhaust, and recovering heat in waste water. By reusing atmospheric beck water 70 percent of water heating energy could be saved. Continuous dyeing in place of the atmospheric beck "batch" type is also more energy-efficient. Drying conservation is obtained through process control and equipment modification including controls to reduce exhaust and recover heat.

utilize predominantly thermal energy which is either transformed and utilized indirectly as steam (e.g., in heating dye liquors) or utilized directly by fuel combustion (e.g., in drying operations).

Conservation opportunities in dry processing (spinning, knitting, weaving, etc.) are not nearly as large since climate control systems and textile fabrication equipment require extensive and costly engineering modifications to significantly reduce energy consumption. Most of the energy required in dry processing is in the form of electricity which also limits energy conservation potential (Georgia, 1979, p. 2). This electricity-intensiveness in dry processing helps explain the increasing textile electricity/output ratios occurring in many developing countries. As the industry expands and plants begin to modernize there is both the introduction of climate control features to increase worker comfort and of electrically operated fabricating equipment. Neither trend should slow for some time yet.

How many of these energy conservation measures cited for the U.S. textile industry are applicable to the textile industries in developing countries? Textile production in the LDCs is generally assumed to be much more labor-intensive and less energy-intensive than that in the United States. Yet the little data available for the United States and three developing countries, shown in table 4-11, indicate that this may not be the case. Specific consumptions in Egypt, India and Bangladesh are all larger than in the United States.

The comparisons, however, must be used with caution. Specific consumption varies widely, not only by process used, but by product made and capacity utilized. For example, energy use is a function of loom time required, which is itself a function of quality type of textile. In addition, the textile industry in most countries is characterized by a multiplicity of establishments unlike the situation in, for example, the steel industry. Consequently, production efficiencies have wide ranges among plants in the same country producing the same type of textile.

Although its one large-scale textile industry is nationalized, Bangladesh has over 140,000 small-scale cotton/wool establishments. In addition there are some seventy-four jute textile mills. The most important explanatory variables for its overall low energy efficiency are first,

Table 4-11. Specific Energy Consumption per Metric Ton of Product in the Textile Industry
(10^4 kcal/metric ton)

United States[a] (1972)	1331
(1976)	1212
Egypt[b] (1975)	1563
India[c] (late 1960s)	1663-1991
Bangladesh[c] (1973 average)	3755
(1973 low)	1462

[a]Office of Business Assistance Programs, Voluntary Business Energy Conservation Program, Progress Report No. 6 (April 1978) p. 55.

[b]Egypt and U.S. Department of Energy, Joint Egypt/United States Report on Egypt/United States Cooperative Energy Assessment vol. 3 (Washington, D.C., GPO. April 1979) pp. 111-12.

[c]Meta Systems Inc. and Montreal Engineering Co., Ltd., Bangladesh Energy Study Appendix I, vol. 1, administered by Asian Development Bank under United Nations Development Program (November 1976) p. 2-297.

significant capacity underutilization caused by unreliable electricity supplies (Bangladesh, 1976, vol. 1, p. 2-290) and second, the use of relatively inefficient coal and firewood fuel sources by composite and specialized mills to produce process steam. This process steam is then used in humidity control, the slashing process and finishing operations (Bangladesh, 1976, vol. 1, p. 2-292).

In Egypt the textile industry is one of the oldest and employs 50 percent of the total industrial labor force. Although synthetic fibers have recently been increasing in importance, most textile production has utilized cotton raw materials and the datum in table 4-11 is for cotton textiles only. As is the case in the United States, most dry processing operations utilize electric power (e.g., electric shuttles and looms) where energy efficiency can improve substantially only through machinery turnover. There remains, however, large scope for energy savings in the wet processing--up to 25 percent--largely through recovery of waste heat and harnessing of exhaust steam. Expelled steam is particularly high; in some

cases temperatures of baths poured into sewers are around 100°C, the temperature of air leaving driers about 135°C, and the temperature of steam leaving agers around 100°C (Egypt, 1979, vol. 3, p. 113).

Another topic of importance is the role of synthetic fibers in the textile industries of developing countries. We already noted the increasing importance of synthetics (polyester and polyester-cotton blends) in Egypt. In Asia, textile manufacturing became the cornerstone of most countries' attempts to industrialize in the 1960s.[13] The importing or local production of inexpensive petroleum-based synthetic fibers appeared to be a modern, attractive alternative to the production of natural fibers. Instead of concentrating on becoming self-sufficient in traditional raw material supplies, many Asian countries opted for synthetic fiber production. After 1973, energy costs, both direct and indirect, rose almost 250 percent. Yet, having made the commitment to synthetics, few Asian countries have been prepared to reverse the trend. Countries like Thailand, which are without domestic petroleum supplies and have largely inefficient production facilities, were hardest hit. Other countries, Korea and Taiwan for example, have rapidly expanded synthetic textile production aided primarily by extremely modern industries. Since they do not have significant domestic oil reserves, this development choice might later come into question. At the minimum, many conservation measures available for traditional textiles are also relevant to synthetic fiber textiles and should be implemented wherever possible. Additionally, advancements in synthetic printing processes and polymer property alterations can also offer significant energy savings to these manufacturers.

Food Processing

Energy consumption in the food processing industry is even more difficult to document than energy consumption in the textile industry. Yet like textiles, food products contribute significantly to the manufacturing output of developing countries. In a sample of fourteen developing countries located throughout the world, food products were either first or second in

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[13] "The Changing Face of Asian Textiles," in Far Eastern Economic Review, vol. 107, no. 13 (March 28, 1980).

importance as a percentage of total manufacturing output for eleven of them (UNIDO, 1979, pp. 87-99). But like textiles, food products are not major energy consumers nor extremely energy-intensive, at least as measured by input-output tables. What then is the significance of energy conservation measures in the food products industry?

In the United States a voluntary target of 12 percent was established for 1980 energy savings in the food industry over 1972 specific energy consumption. Recently published data give every indication that the net energy improvement target will easily be met (Office of Industrial Programs, 1979, p. 9). Should this be the case, industry efficiency will result in energy savings of 143 trillion Btu per year--the equivalent of 62,000 barrels of oil per day. Although there exist few means for gauging the conservation potential in the developing countries, these figures for the United States, coupled with the overall importance of the foods industry in many LDCs, indicate it may be significant.

Potentially important conservation techniques available to the food industry include waste heat recovery and improved heat transfer in drying operations (ERDA, 1976, p. 3). Improvements in electrical energy usage and increased boiler and steam efficiency also offer potential energy savings as does the upgrading of insulation and linings in furnaces, boilers, kilns, ovens, cookers, and other process equipment. Improvements in evaporation and liquid condensation processes, although varying from process to process, offer large savings potential. In those industries which generate a large amount of crop wastes (e.g., sugar processing) there is ample evidence that the wastes might be best utilized as boiler fuels for steam production.[14] In general, however, housekeeping measures can offer the best conservation prospects in this highly diversified, disaggregated industry where energy costs have historically been a small fraction of total production costs.

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[14]The utilization of crop wastes, however, will not always be to the benefit of the food industry. In Peru, for example, bagasse has traditionally been used as a fuel except where it was used as a chargestock for paper plants. With the increasing use of bagasse for papermaking, it is anticipated that all bagasse will have been removed from fuel use by 1985, necessitating replacement with petroleum-based fuels (Peru, 1979, vol. 3, p. 76).

Conclusions

This chapter reviewed the specific energy requirements, that is, energy intensities, of several manufacturing subsectors among several industrialized and developing countries. At the outset it was determined that the major energy consumers in the industrialized countries also accounted for the majority of industrial energy demand in developing ones. Specifically, these include iron and steel, cement, pulp and paper, chemicals, and basic metals. Since food products and textiles are generally of extreme importance in total LDC manufacturing output these also were reviewed.

Energy savings through housekeeping measures and minor investments were shown to be possible in all industries, but new technologies are expected to be the major factors in determining long-run developing country industrial energy demand. Of course energy efficiency is not the only factor in technology choice, nor should be. For example, the scarcity of scrap and coking coal has led to an increasing reliance on currently more energy-intensive fuel-injected BF/BOF processes and directly reduced iron utilization. In cement production the dry process in conjunction with suspension preheating is much more energy-efficient than the old wet process, but high capital costs have constrained plant conversions in several developing countries.

Integrated pulp and paper mills are more energy-efficient than non-integrated mills. Although having greater energy intensities than mechanical pulping, chemical pulping will increase in importance because of its ability to utilize internally generated energy. It is possible for such plants to become totally energy self-sufficient.

New technologies can be expected to provide almost all future energy savings in aluminum production, but the paucity of energy data is particularly noticeable in the extractive/metals industries. Energy savings in the chemical industry have historically resulted from housekeeping measures and the normal stages of technological progress of production--small energy-inefficient production followed by large-scale continuous energy-efficient production.

Given the heterogeneity of the industries, energy conservation in the food and textiles industries results mostly from housekeeping measures and small investments. The role of synthetic textiles warrants greater study.

Energy-intensiveness in LDC manufacturing sectors, except where the capital stock is relatively new, is usually greater than in similar industries of developed countries. Factors which often were seen as reducing an industry's energy efficiency include capacity underutilization and the lack of scrap feedstocks. Better insulation and waste heat/gas recovery, while important in all countries, could prove especially beneficial in many LDC industries. Interfuel substitution, often a result of sound economic decision making, may nevertheless conflict with strictly energy conservation efforts. There remains a great need for further plant-by-plant study on all of these aspects of industrial energy conservation.

Chapter 5

SUMMARY AND CONCLUSIONS

This paper detailed the use and potential conservation of energy in the industrial sector of developing countries' economies. It began by presenting both the pre- and post-embargo records of industrial energy demand in several industrialized and developing countries. Aggregate growth trends and cross-country comparisons of energy inputs per dollar value of output were given. Descriptions of the structure of industrial output and industrial energy demand were presented for Brazil, India, Kenya and Korea. Finally, industrial processes in the major energy-consuming manufacturing subsectors were reviewed, indicating areas and measures of potential energy conservation.

Aggregate Industrial Energy Demand

Prior to the 1973 oil price rise industrial energy demand was growing quite rapidly in both industrialized and developing countries. In the developing countries for which data are available, the growth rate of industrial energy demand was generally 10 percent or more. In most cases industrial energy demand was growing faster than energy consumption in other sectors of their economies. After 1973 industrial energy growth rates fell significantly in the developed countries--in fact in Germany and the United States industrial energy demand fell absolutely as well--but not nearly so much in the developing countries. In India and Portugal the rate of industrial energy consumption actually accelerated after the price increases.

In the developed economies, industrial output, measured in physical terms, generally stabilized after 1973 and was accompanied by a slowing in industrial energy demand. In the developing countries, continued rapid expansion of industrial production meant increasing industrial energy requirements. Changes in energy consumed per unit of output varied among all countries, but for most LDCs such unit energy use in 1976/1977 was above 1973 levels.

Energy consumption per million dollars of industrial output also varies greatly among countries and over time. Part of the explanation for such variances is the composition of industrial output--some industries being more energy-intensive than others. Part of the explanation seems to be the fuel mix--some countries using relatively greater proportions of thermally inefficient fuels than others.

In the 1967-73 period, industrial electricity demand in the developing countries grew more rapidly than electricity demand in the industrialized ones; and also more rapidly than the developing countries' total electricity demand. Because of a large hydroelectric role, expansion of electricity generating capacity, and declining real electricity prices--resulting from high inflation rates and subsidized pricing policies--electricity consumption continued to rapidly expand after 1973 in the developing countries. Consequently, many manufacturing subsectors--food, textiles, iron and steel, and chemicals--experienced rising ratios of electricity consumption per unit of manufacturing output.

Structural Characteristics

The structure of industrial output and industrial energy inputs were presented for Brazil, India, Kenya and Korea. The record appears quite mixed as to the effect of these factors on total industrial energy demand. Even at the most aggregate level, while there appears to be some correlation between growth rates of industrial output and growth rates of industrial energy demand, the relationship is not consistent among countries. As might have been expected, Korea, the fastest growing country reviewed, had the most rapid rate of industrial energy demand, and India experienced the slowest growth rates in both industrial output and energy demand. By contrast, however, Kenya had an industrial energy demand growth rate between 1967-76 twice its rate of industrial output.

The fact that Korea was industrializing the most rapidly of the four countries explains its high rate of industrial energy demand growth. The fact that much of this growth occurred in energy-intensive heavy industries reinforces this pattern of increasing energy demand. At the same time its industrial energy consumption/output ratio is relatively low. This apparent inconsistency would seem to be explained largely by the fact that Korea was able to utilize newer, energy-efficient equipment in its production processes, especially in its more dynamic subsectors of machinery and equipment.

Similarly in Brazil, its structural emphasis on heavy industry explains its high industrial energy requirements, while the utilization of new industrial equipment and shift from traditional to commercial fuels helped keep its industrial energy/output ratio low. Expectations are that Brazil's energy-intensive subsectors will continue to grow the most rapidly so that its changing industrial structure might determine total industrial energy demand even more in the future than had previously been the case.

In India the fuel mix, which is dominated by the use of thermally less efficient coal, would seem to explain a large part of its high industrial energy/output ratio. Most manufacturing subsectors, both light and heavy industries, grew slowly during the 1967-76 period, as did total industrial energy demand.

Kenya's structure of industrial output seems most clearly related to its rapid industrial energy growth. While light industries are dominant in its total output, petroleum refining has played a major role in its economic structure since the 1960s. Additionally, in the light industries of food and textiles high energy requirements per unit of output have resulted from severe excess capacity. The large use of noncommercial fuels also contributes to its relatively high industrial energy demand.

In summary, these four countries exhibit extremely divergent patterns of industrial growth and energy consumption. While the structure of output explains part of the varying industrial energy requirements, this brief review indicates that the intensity of production--determined by both the fuel mix and the type of equipment used--are also rather important.

Energy Intensity

There exist large differences in energy requirements per unit of output both among and within manufacturing subsectors which certainly indicate concrete possibilities of energy savings. To date most savings in the developed countries have resulted from rather easy to implement, inexpensive "housekeeping" measures. There would seem to exist similar energy saving opportunities in many developing countries. Yet other factors such as increased capacity utilization and waste heat recovery were consistently seen as offering significant energy savings.

In many industries new process changes were shown to have the greatest impact on total industrial energy demand. In some respects this is good since many developing countries are still in the early stages of development plans and they might be able to incorporate energy conservation measures into these plans. On the other hand, process changes by their nature tend to be costly at the outset and, for some countries, this places a prohibitive price on utilizing new energy-efficient processes over more established technologies. Additionally, some of the newer technologies, while sound from an economic viewpoint, are not the most energy-efficient. Consequently, a goal of energy conservation must be secondary in deciding which technology should be used.

Specifically, seven industries were reviewed. Collectively they account for the bulk of industrial energy demand. They are iron and steel, cement, pulp and paper, chemicals, basic metals, food products and textiles.

In countries for which data are available, specific energy requirements per ton of steel output varies considerably. Newer electric arc and basic oxygen furnace processes are less energy-intensive than the old open hearths. Yet, since coking coal and steel scrap are generally scarce, several developing countries have taken steps such as injecting fuel in the furnace tuyeres and relying on directly reduced sponge iron to overcome their particular resource scarcity problems. Both methods are currently more energy-intensive than the traditional blast-furnace/basic oxygen furnace process.

In cement production, the dry process, in conjunction with suspension preheating, is much more energy-efficient than the old wet process. However, high capital costs have constrained plant conversions in several

developing countries. Also, the choice of kiln fuel was seen to influence the energy efficiency of cement production. There appears to be large conservation potential in utilizing steel slag as a cement raw material input.

Within the pulp and paper subsector, integrated pulp and paper mills are much more energy-efficient than nonintegrated mills. Additionally, even though chemical pulping has higher energy intensities than mechanical pulping, the chemical process will increase in importance because of its ability to utilize internally generated energy. It is possible for such plants to become totally energy self-sufficient.

Energy savings in the chemical industry have historically resulted from housekeeping measures and the normal stages of technological progress of production--small energy-inefficient production followed by large-scale continuous energy-efficient production. In the manufacturing of fertilizers, phosphatic nutrients require much fewer energy inputs than do nitrogenous nutrients. The type of fuel used in producing nitrogenous nutrients is extremely important with regard to specific energy requirements. Natural gas is the preferred fuel source or, if not available, countries would best utilize naphthas or fuel oils over coal or water electrolysis.

Much more data are required covering energy efficiencies in basic metals production, from mine to fabricated product. The heterogeneity of the food and textiles industry also warrants much more detailed study. All three industries are important in developing countries. Energy conservation in the former is likely to result primarily from process changes; energy conservation in the latter two from housekeeping measures.

Appendix A

INDUSTRIAL ENERGY AND OUTPUT DATA

Historically, energy data were collected to document supply development, to determine the growing supply of electricity or reserves of oil, for example. Consumption data, especially end-use consumption, were largely ignored. Only after the 1973 oil embargo did the Organization for Economic Cooperation and Development begin to collect such cross-country time series data for selected developing countries on a comparable basis, but the level of disaggregation could be greatly improved. Although many individual establishments do attempt to gather energy use data, quite often this information is not available to independent researchers.

Recently, there have been other energy data tabulations and energy assessments. For example, the Department of Energy in its international cooperative energy assessments has documented energy use data in Egypt and Peru both for individual establishments and on an industry wide basis. Similar data collection and energy use assessments are to be published for Korea, Argentina and Portugal.

In chapter 2 on aggregate industrial energy use, several countries' energy consumption index/industrial production index ratios and energy use/industrial output (tons oil equivalent per million $1977 dollars) ratios are presented to provide time series and cross-country comparisons, respectively. Given the spotty nature of energy demand data, the desire was to utilize a single source which broke out industrial consumption from total demand for several countries. The tabulations were to be at least theoretically consistent to allow such cross-country comparisons even though specific detail for some manufacturing industries might be better obtained from single country reports.

Industrial Energy

The only source providing such an industrial energy demand disaggregation over time, 1967-77, is an OECD report on 16 developing countries of which data on only six of them appear reliable and comprehensive enough for our calculations.[1] The consumption data is disaggregated into an energy sector, industry, transportation, other (household/commercial), nonenergy uses, and unaccounted for. The two sectors which are specifically included in our calculations of industrial energy consumption are the industrial sector and the energy sector itself.

OECD energy consumption data in the industrial sector apparently include all energy usage in the manufacturing industry and the nonenergy mining industry. That is, the energy consumption of both heavy and light industries and the extractive sectors are included. (Unfortunately the data do not include energy used as part of any cogeneration process.) More technically, the data are for the one-digit International Standard Industrial Classification (ISIC) numbers 2-3, excluding, however, the activities of the energy industry.

For consumption in energy industries a section on energy requirements for the primary energy sector is separately listed. Essentially, energy use in the energy sector is a result of either (a) own use activities, (e.g., electricity consumption for running plant lights) or (b) transformation losses. The latter includes heat losses incurred in the generation of thermal electricity--this does not include fuels used in autogeneration--losses incurred in the production of city gas, refinery losses, electricity transmission and distribution losses, and losses as a result of coal conversion and natural gas production and transportation use. While conservation potential exists in both types of energy use--improved electricity generating technology on the one hand, and energy conservation through "housekeeping" measures on the other hand, for example--we keep with the example provided in recent studies on energy use in the industrialized countries and try to exclude transformation losses from our calcula-

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[1] International Energy Agency, (1979b); also, International Energy Agency, Energy Balances of OECD Countries (various issues) are used for Turkey, Portugal, United States, Germany, Italy and Japan.

tions of industrial energy.[2] Occasionally this exclusion may not be justified if the structure of a developing country's industrial sector is such that it has a large or growing energy industry.

To separate energy consumed in own-use activities from losses incurred in transformation, several conventions are applied to the OECD data. Electricity generation, which accounts for the bulk of all transformation losses and consequently far outweighs its own-use energy consumption, is excluded from the industrial energy calculations. Similarly, gas manufacturing losses--largely conversion losses of coal into gas--are also excluded.

Energy use by petroleum refineries, on the other hand, is included, since very little oil is actually lost in its conversion processes, but rather own-use consumption predominates. Finally, OECD data include a section on energy sector use and loss which includes energy sector consumption, except transformation losses. The amounts are added to our totals. The result of these adjustments is that industrial energy consumption includes the industry sector and the own use of energy in the energy sector as much as possible. Also, the data include estimates for both commercial and traditional fuels consumption.

Useful Energy

In table 2-3 our usual measurements of energy consumption, all fuels converted to metric tons oil equivalent, are adjusted by their various thermal efficiencies to arrive at "useful" energy consumption. The OECD aggregate industrial energy consumption data described above, net of consumption by the energy industries, are multiplied by the different fuel efficiencies listed in table A-1.

Industrial Output

To exhibit changes of energy requirements per unit of industrial output two conventions may be adopted. Each has its drawbacks; each has its

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[2] See, for example, Darmstadter and coauthors (1977) and Dunkerley and coauthors (1980). In these publications the five major end-use sectors for which energy consumption is analysed are transformation losses, nonenergy uses, industry, transport, and residential/commercial uses.

Table A-1. Thermal Efficiencies of Fuel Use in Industry, Excluding the Energy Sector

Solid	.70
Liquid	.80
Gas	.85
Electricity	.99
Noncommercial[a]	.55

Source: William D. Nordhaus, ed., Proceedings of the Workshop on Energy Demand, International Institute for Applied Systems Analysis (Laxenburg, Austria, IIASA, 1975) p. 527.

[a]RFF estimate.

advantages. Available in the United Nations Statistical Yearbook is an industrial production index extending back over several decades. The index measures changes of real output in physical terms. Since constant dollar industrial output figures are generally not available in most countries, a physical output index overcomes problems of deflating current dollar sales and avoids the common assumption that value added remains a constant proportion of gross sales. As such, a ratio of an industrial energy consumption index/industrial production index captures real changes of energy required per unit of output over time.

A major drawback is that it is not possible to make cross-country comparisons of such industrial energy intensity ratios. Because of this, a national income accounts approach is adopted. By dividing absolute industrial energy demand by a constant dollar measure of industrial output, cross-country energy intensity comparisons may be made regardless of the size of the economy or year of collation.

In determining industrial energy/GNP intensities it is necessary to portion off that part of GNP which was generated in the industrial sector. To do this, United Nations data on gross domestic product by economic activity is utilized.[3] The UN data provide a percentage distribution of

[3]United Nations, Statistical Yearbook (various issues).

GDP in current producer values for both total industrial activity and the manufacturing industries. The broader category includes not only manufacturing, but also mining and quarrying, electricity, gas and water. There are two reasons for using the broader category. First, the OECD data on industrial energy consumption include the mining industry and in many developing countries the extractive sector is not only of major economic consequence but is also an important consumer of energy. Second, even though the UN data include the utilities (ISIC 4) and the OECD data do not, the inclusion of own use by the energy sector should eliminate some of this industrial GDP output overcounting. We then multiply World Bank GNP constant dollar figures by the UN percentages of industrial value to obtain a constant dollar measure of industrial output. (The only exception to using total industrial activity percentages is when useful energy/output ratios are derived. Since the useful energy calculations exclude the energy sector, economic activity percentages of manufacturing only are used.)

Several problems remain. While the UN derives its percentage measures of economic activity in current currency terms, we apply them to constant dollar values. This process will cover over differences in inflation rates between the industrial sector and the rest of the economy. Generally, at least in the United States, overall inflation is greater than that in the industrial sector and therefore the derived industrial constant dollar output will go up less than if a true industrial deflator could be applied. It is not possible to determine which countries are most adversely affected by this methodology. Also, the industrial output percentages are measured in Gross Domestic Product terms while the World Bank constant dollar data are of Gross National Product. Their differences, and therefore any error incurred, are usually not significant.

Finally, there is the problem of converting several countries' national output into a single currency given the complexities of exchange rates and foreign currency denomination. Any of several conventions could be used including, for example, the purchasing power parity method developed by Irving Kravis. For this paper we have utilized World Bank constant

dollar GNP data and therefore the World Bank's exchange rate conversion methodology.[4]

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[4] For a discussion of the World Banks' methodology see World Bank (1980a).

Appendix B

SPECIFIC ELECTRICITY DATA

The electricity sector is the one energy industry for which collection of consumption data has a long record. This is because of the dominant role of governments within the industry, because of the important role of electricity in overall urbanization/industrialization plans, and because of the high cost and long lead times required in establishing an electrification network. Consequently, one might expect that electricity consumption within the industrial sector, and even within specific manufacturing subsectors, would be more readily available than are data for total energy demand. Occasionally this is the case; often it is not.[1]

Available from the United Nations Yearbook of Industrial Energy Statistics are data, generally down to the 4-digit level, of electricity consumption, gross output, value added and an index of industrial production for different industries. The data are incomplete, do not extend back before 1963 and the definition of coverage often changes over time. For most countries electricity consumption by industry is only sporadic if available at all. For others, industrial indices are not presented. In several cases, although description of coverage remained unchanged, a jump in the electricity consumption from one year to the next which is not accompanied by a significant change in output renders the comparability of data suspect. Consequently, data for only ten developing countries appear

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[1]For example, it was related to us that in the Dominican Republic the largest manufacturing companies maintained no records of electricity use and that the Government Electricity Agency also had no records of sales and distribution.

both complete and reliable enough for comparative purposes. Even in these countries, the ratios are presented more for description than detailed analysis.

Despite these problems it is possible to obtain a feeling of changing industrial electricity intensities by relating the index of industrial production (which measures physical output) to the index of electricity consumed in each observed industry.[2] But by relating indices it is not possible to make intercountry comparisons or even cross-industry comparisons beyond noting that one industry is becoming more efficient and another apparently is not. Nevertheless the calculations do give indications of changing intensities and therefore changing efficiencies of use. If, for example, the index ratio declines over time, then it would be fair to say that something--changes in relative prices, changing technology, etc.--had fostered declining electricity use relative to output, that is, conservation. If, on the other hand, the ratio increases over time, then that particular industry is becoming more electricity intensive. The question then becomes why these changes have occurred and what might be done to encourage additional industrial energy conservation efforts.

An alternative approach might be to compare the electricity use of an industry to its money value added or gross output value rather than industrial production index. Gross output comparisons would probably be of limited use since over time money values of some inputs undoubtedly change relative to other inputs and to an industry's own values added, and would therefore be most misleading as a measure of changing electricity intensity.

An additional drawback in utilizing money value of gross output data is also germane to the inappropriateness of using money value added quantities. Although this would avoid the problems of inadvertently assuming improved electricity use in one industry where it was actually due to a change of inputs from other industries, the utilization of value added data reported in current producer value figures has its own problems. Without changing the current money values into constant currency the

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[2]The discussion which follows is not limited to electricity use, but could pertain to total energy consumption as well.

Table 3-1. Electricity Consumption and Industrial Production Indices of Several Manufacturing Industries

	1963		1967/68		1970		1973		1974		1975		1976		1977	
	Kwh[a]	Prod. In.[b]	Kwh	Prod. In.	Kwh	Prod. In.	Kwh	Prod. In.	Kwh	Prod. In.	Kwh	Prod. In.	Kwh	Prod. In.	Kwh	Prod. In.
Brazil																
Food[d]			503	76	570	100	769	129	845	137	897	139	992	155	1107	164
Textiles			1009	84	1225	100	1516	127	1617	124	1654	128	1755	136	1695	137
Paper			456	79	606	100	790	126	876	131	881	112	992	135	999	138
Chemicals			1007	68	1523	100	2439	154	2747	167	3020	172	3397	195	3563	202
Iron and steel[e]			1531	70	2151	100	3427	138	3935	145	4027	158	4920	178	5436	195
All manufacturing			6202	70	8498	100	12647	148	14082	160	14685	166	16695	185	18372	190
Colombia																
Food	225	51	275	83	460	100	459	133	517	141	549	166	567	166		
Textiles	381	75	388	81	532	100	653	145	692	133	658	125	705	138		
Paper	106	44	140	66	197	100	238	146	320	150	281	144	341	152		
Chemicals	172	62	220	77	171	100	560	133	470	146	556	144	694	153		
Petroleum refining	102	64	128	86	155	100	269	122	221	125	233	122	272	126		
Iron and steel[f]	99	72	193	77	246	100	294	101	371	104	411	107	371	102		
All manufacturing	1752	66	2437	81	2729	100	3719	129	4092	136	4132	137	4448	147		
Dominican Republic																
Food	112	75	76	81	93	100	130	115	134	120	137	116	140	131	149	132
Textiles	6	59	5	58	7	100	9	93	9	85	8	100	9	123	13	131
Paper	2	42	10	63	12	100	15	146	27	145	27	109	29	141	28	210
Chemicals	6	48	7	51	12	100	15	167	14	154	11	172	12	200	13	214
All manufacturing	164	70	152	77	210	100	305	133	334	143	331	149	341	161	408	178
Ecuador																
Food	37	51	52	82	76	100	95	119	98	128	107	130	158	143		
Textiles	23	44	38	78	51	100	64	142	79	151	78	160	84	162		
Petroleum refining	9	46	12	70	19	100	22	130	21	146	22	165	22	188		
All manufacturing	113	46	183	76	256	100	353	131	384	149	435	162	514	178		
El Salvador																
Food					63	100	75	80	63	74	79	88				
Textiles					64	100	90	130	91	112	93	112				
All manufacturing					202	100	274	119	288	111	311	128				
Korea[c]																
Food					522	100	637	113	705	111	771	120	889	159	1029	204
Textiles					1093	100	1456	125	1718	129	2240	164	2677	215	3122	232
Paper					447	100	560	132	710	159	752	164	888	198	1042	249
Chemicals					993	100	1191	123	1324	139	1641	182	1739	225	1960	265
Iron and steel					625	100	864	158	1282	302	1463	323	1930	455	2321	552
All manufacturing					6277	100	8229	135	9707	175	11262	208	13533	283	15792	321

Mexico																
Food			451	83	558	100	586	[illegible]	652	116	635	120	762	127		
Textiles					485	100	548	131	565	134	573	139	585	132		
Paper			728	76	991	100	1139	115	1172	129	1171	121	1248	138		
Chemicals					673	100	938	148	1132	157	1220	164	1468	186		
Iron and steel			1840	77	2569	100	3142	124	3454	139	3597	138	3826	141		
Philippines																
Food			422	99	512	100	1491	178	902	121						
Textiles			316	102	337	100	426	136	520	124						
Paper			166	108	193	100	512	100	469	97						
Chemicals			291	87	212	100	381	170	349	275						
All manufacturing			2357	96	2807	100	5838	154	5598	138						
Portugal[f,g]																
Food			156	102	188	100	304	132	284	130	331	156	342	163	383	178
Textiles	373	65	556	83	656	100	841	142	861	147	728	122	756	124	810	121
Paper	127	36	249	61	408	100	495	116	519	144	414	132	516	139	552	159
Chemicals			272	89	222	100	746	132	938	135	968	130	791	144	961	158
Iron and steel	181	70	215	81	306	100	506	164	505	142	474	110	507	125	658	163
All manufacturing	1272	55	2207	74	2683	100	4444	137	4779	140	4566	132	4692	139	5372	142
Tunisia																
Textiles			17	81	17	100	25	119	38	121	42	110	45	97		
Paper					14	100	75	132	99	130	57	130	58	127		
Chemicals			15	86	68	100	81	118	120	128	91	125	133	124		
All manufacturing			116	90	244	100	394	125	514	134	487	135	557	143		

Source: United Nations, Growth of the World Industry, vol. 1 (New York, UN) (various editions), and Yearbook of Industrial Statistics, 1977 Edition, vol. I (New York, UN, 1979) and 1978 Edition, vol. 1 (New York, UN, 1980).

[a]Million KWh.

[b]Industrial Production Index.

[c]Korean 1970 data are actually for 1972 and related indices derived where 1972 = 100.

[d]Food, beverages and tobacco.

[e]Iron and steel, non-ferrous metals, and metal products.

[f]Production index for iron and steel, and non-ferrous metals.

[g]For Portugal, 1976 and 1977 data compiled by a different classification than was used in previous years.

energy ratios are meaningless and yet to deflate a single industry's value added quantities by a general wholesale or consumer price index can cover the relative input price differences/changes which justify changing input use in the first place. That is, an economically rational decision to increase electricity use by an industry as a result of increasing (inflated) costs of capital, labor or other inputs, if not properly deflated, would appear simply as a decrease in efficiency and point to a misleading conclusion that the particular industry is a prime candidate for conservation measures. It may or may not be, but such construed electricity intensity ratios are not reliable indicators of such need. Unfortunately, industry-specific inflation indices are relatively primitive even in the United States. They are virtually nonexistent in the developing countries.

To conclude, electricity/value added ratios would have been preferable measures of electricity efficiencies allowing time series comparisons for both cross-industry and--if properly converted--cross-country. However, for the reasons cited above, the industrial production indices in relation to a derived index of electricity use by industry is used instead. The results, presented in chapter 2, while incomplete, are nevertheless informative. The electricity data and industrial output indices are presented in table B-1.

Appendix C

CONVERSION FACTORS

Table C-1 lists the conversion factors utilized throughout the report for changing original source data into a common denominator, kilocalories (kcal). Unless noted otherwise no adjustment has been made to include transformation losses incurred in generating electricity.

For specific energy consumption calculations one short ton equals 2000 pounds, one metric ton equals 2204.6 pounds, and one long ton equals 2240 pounds.

Table C-1. Conversion Factors Into and From Kilocalories

To kilocalories

1 Metric Ton Oil Equivalent (toe)	$= 1.06 \times 10^{7}$ kcal
1 Metric Ton Coal Equivalent (tce)	$= 7.21 \times 10^{6}$ kcal
1 Joule (J)	$= 2.389 \times 10^{-4}$ kcal
1 Giggajoule (GJ)	$= 2.389 \times 10^{5}$ kcal
1 British Thermal Unit (Btu)	$= 2.52 \times 10^{-1}$ kcal
1 Kilowatt Hour (KWh)	$= 8.6 \times 10^{2}$ kcal

From kilocalories

1 kcal = 9.434×10^{-8} toe

1 kcal = 1.387×10^{-7} tce

1 kcal = 4.186×10^{3} J

1 kcal = 4.186×10^{-6} GJ

1 kcal = 3.986×10^{0} Btu

1 kcal = 1.163×10^{-3} KWh

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