Working Paper

THE IMPACT ON ENERGY CONSUMPTION OF CHANGES IN THE STRUCTURE OF US MANUFACTURING

PART I: OVERALL SURVEY

Claire P. Doblin

February 1987
WP-87-04

International Institute for Applied Systems Analysis
A-2361 Laxenburg, Austria

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Report prepared for the Electric Power Research Institute (EPRI) under contract agreement TPS 84-606 and with a financial contribution from Kernforschungsanlage Jülich (KFA).

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Foreword

Since the first oil price escalation of 1974, there has been considerable reduction in total energy use per unit of total output. This development has many names: increasing energy conservation, increasing energy productivity, or, conversely, decreasing energy intensity.

Claire Doblin's study is concerned with the empirical analysis of factors *directly* responsible for this trend in the US manufacturing sector during the 1974-1980 period. Escalating oil prices are commonly believed to have prompted energy savings and conservation in the manufacturing sector – just as they did to some extent in the case of household fuels and gasoline demand. However, the decreasing energy intensity of US manufacturing (and US industry) is a *long-term* development, coinciding at times with falling or stable energy prices, e.g., in the post-World War II period. In other words, the *current* energy intensity decrease was not created by rising oil prices alone. Hence for this period in history, at least, the role of price-induced substitution (as implied by the incorporation of energy resources in the production function) is less important than has some times been assumed. This is so because the forces at work to shape the energy intensity of the industry sector reflect the characteristics of an aging industrial society – the shift from energy- (and labor-) intensive industries toward industries with lower energy (and labor) requirements and higher value added. This aging or maturing of the industrial sector is in sharp contrast to the rapidly increasing energy intensity of developing countries such as Mexico and Brasil.

The analysis is based on detailed statistics on structure and technology impact at two levels: aggregate of all sectors (total manufacturing) and the most energy-intensive industries that together absorb about 80% of total manufacturing input. The conclusions, and the underlying data, should be useful for further work in the study of industrial change as well as energy modeling.

T.H. Lee
Director

Acknowledgement

I wish to thank the Electric Power Research Institute (EPRI) and the Kernforschungsanlage Jülich (KFA) for their financial support. My thanks go also to the International Institute for Applied Systems Analysis (IIASA) which enabled me to carry out the research, and to the many persons inside and outside the Institute who so patiently read the drafts and gave me their comments and suggestions. I am especially indebted to the late Ed Schmidt of IIASA, for the time he gave me and the encouragement to go on with the task.

Claire P. Doblin

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THE IMPACT ON ENERGY CONSUMPTION OF CHANGES IN THE STRUCTURE OF US MANUFACTURING

PART I: OVERALL SURVEY

Claire P. Doblin

1. INTRODUCTION

ENERGY INPUT, GNP, AND INDUSTRIAL OUTPUT

In the years of rapid economic expansion that followed World War II, total consumption of all forms of primary energy and Gross National Product (GNP) in constant prices expanded at much the same rates. But since the oil embargo of 1973, the growth rates of energy and GNP have diverged, and the energy used per unit of output for the economy as a whole measured by the energy/GNP ratio has continuously decreased. This decrease is commonly referred to as declining energy intensity; conversely, it also signifies growing energy productivity. For purposes of the analysis, both terms are used alternately.

There is a strong belief shared by economists and the public at large that energy productivity in the US and other Western industrialized countries was increasing because of conservation measures and energy savings adopted in response to the high and rising costs of energy. However, the post embargo period, specifically the decade from 1974-1984, was not the first time rising energy productivity has been observed. Sam H. Schurr, in a pioneering work *Energy in the American Economy* (Schurr, 1960), and more specifically, in his 1982 lecture *Energy Efficiency and Productive Efficiency: Some Thoughts Based on the American Experience* (Schurr, 1984), shows, *inter alia*, that there had previously been a long period (1920-1953) of growing energy productivity of the US economy (energy/GNP ratio) and the industrial sector (energy/industrial output ratio).

Since the first oil price shock in 1973, the energy demand of the industrial sector has decreased more than that of the economy as a whole. This is true not only for the US but for other industrialized countries as well. Figure 1 shows the growth of energy consumption in industry and other sectors in the US, the FRG, France, and the UK. In the USSR (not shown in Figure 1), the growth of energy consumption in the industrial sector is also trailing the national total – though both are still rising.

This analysis traces the factors primarily responsible for the acceleration of energy productivity in US manufacturing, which represents about 80% of US industry. An attempt was made to quantify the impact of several factors that influence the industrial energy intensity. These are: compositional, or as some say, structural changes in the output mix; technological changes in manufacturing processes to improve fuel utilization efficiency; the special role of electricity in enhancing energy productivity; and energy savings resulting from import penetration of domestic markets for energy-intensive products. These various factors were investigated in case studies of primary metals, chemicals, petroleum refining, paper, and cement.

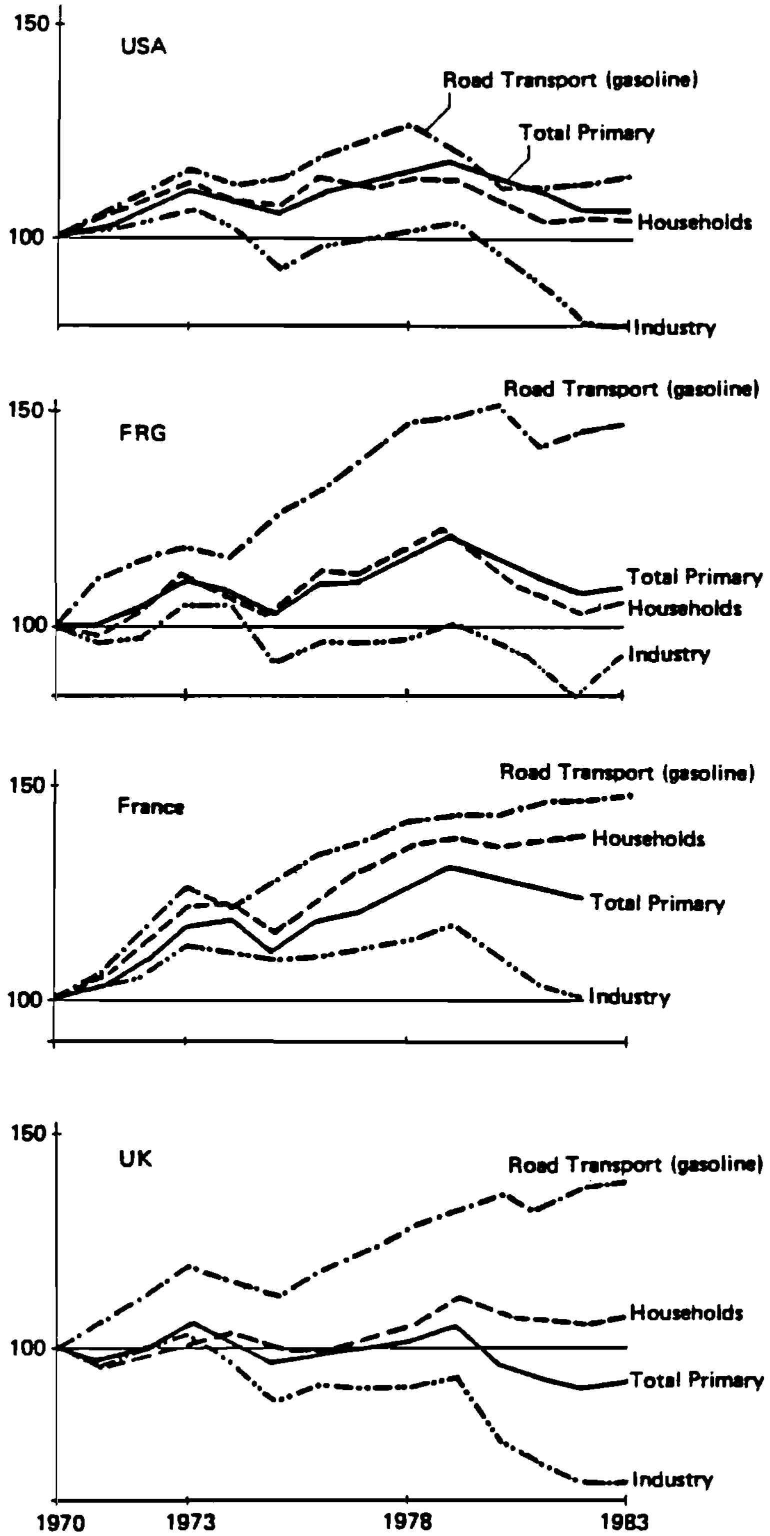

FIGURE 1. Total primary and sectoral energy consumption in four countries, 1970-1983 (index numbers, 1970 = 100).

The case studies and a review of the structural changes in the volume of manufacturing production are contained in Part II of this report.

2. HISTORICAL TRENDS OF ENERGY PRODUCTIVITY GROWTH

2.1. Compilation of Indicators

The analysis of energy productivity in the manufacturing sector is handicapped by the lack of annual data for purchased energy for heat and power in the pre-1974 and post-1981 periods, where such data are available only at five-year intervals as part of the full Census of Manufactures. Moreover, the input of energy used as raw materials (feedstocks) had to be partially estimated from industry sources because it was (till now) not adequately covered by the Censuses[1] (see Appendix Tables 1, 2, and 3).

Industry Sector

While there are serious gaps (time and other deficiencies) in the *manufacturing* sector's energy input, the *industry* sector's consumption of all forms of energy is compiled annually since 1949 – first by the Department of the Interior, and later by the Department of Energy (DOE) under the series of "Consumption of Energy by End-Use Sectors" (US Department of Energy, Energy Information Administration, 1985). These series are in primary energy equivalents and implicitly include energy used as raw materials, as well as losses in electricity generation and distribution. However, it should be noted that by DOE definition of industry, the energy input of agriculture, mining, construction, electricity, and gas utilities are inextricably lumped with that of manufacturing. Still the energy productivity trends in the industry sector can serve as a guide to the developments in total manufacturing. This is so because manufacturing absorbs the major share of the industry sector's energy input (80%). Moreover, the Federal Reserve Board (FRB) production indices for industry and manufacturing follow quite similar growth trends. See Figure 2 for the industry sector's energy productivity growth, compiled from the above discussed DOE and FRB indices.

This shows that energy input per unit of industrial output decreased, and energy intensity decreased while energy productivity *in*creased over the entire period of the study (1958-1984). Further, energy productivity increased most rapidly from 1980-1984, which included years of severe recession following the second oil price explosion in 1979. This increase in energy productivity of the early 1980s is in contrast with the slight decrease of energy productivity observed during the recessions of 1969/1970 and again 1975, after the first oil price shock of 1974, when a slump in industrial production and concomitant falling capacity utilization forced an increase in the amount of energy used per unit of output.

Manufacturing

The manufacturing sector's real gross output (sales values at 1972 prices) was plotted against the growth of "final purchased energy for heat and power" and "aggregate energy input in primary energy equivalents". See Figures 3 and 4, based on Appendix Table 2, with data for selected years since 1967.

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[1]Hydrocarbon and fuels used as raw materials were collected in a special enquiry by the Census for the Department of Energy (DOE) pertaining to the years 1979 and 1980. See this discussed in Appendix 1 (Methodology).

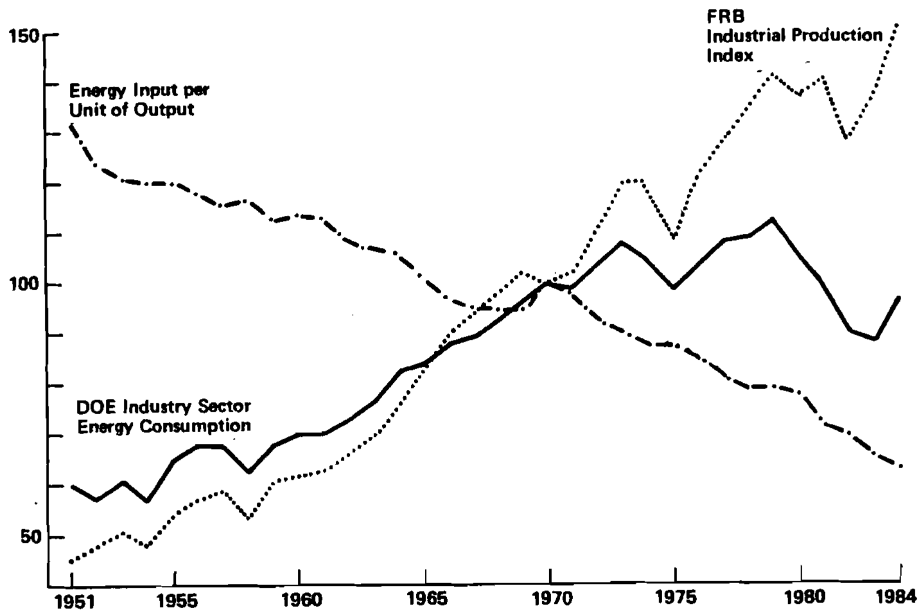

FIGURE 2. US. Industry sector. The growth of production and energy input since 1951 (index numbers, 1970 = 100). SOURCE: Appendix Table 4.

A comparison of the two energy measures shows that since the mid-1970s purchased energy for heat and power tended to fall more rapidly than primary aggregate. The reasons are twofold: demand for hydrocarbon feedstocks for chemicals and petroleum refining grew faster than purchased energy for heat and power.[2] As stated by industry sources, this was due in part to the price factor, favoring hydrocarbon feedstocks over petroleum products – in cases where feedstock (as for example liquid petroleum gas (LPG)) could substitute for petroleum products. Secondly, the electricity input, when measured in primary energy equivalents and including losses in generation and distribution, grows faster than delivered electricity – a matter not to be overlooked with growing electrification.

Thus, since the mid-1970s, energy productivity tended to follow a slower course when based on primary aggregate energy input, and a faster course when based on final purchased energy, as derived from the Census (see again Figures 3 and 4).

2.2. Comparison of US Energy Productivity Compilations

The greater growth of energy productivity in manufacturing was also observed in the results of research based on Census energy input and

- Value added, studied by Myers and Nakamura (1978) for the years 1967-1976;
- Values of shipments at 1972 prices, in the study conducted by Samuels et al. (1984), who used a depression year as basis for their 1975-1980 observations; and

[2] See also statement on feedstock input by the chemicals industry in US Department of Energy/Energy Information Administration (1983).

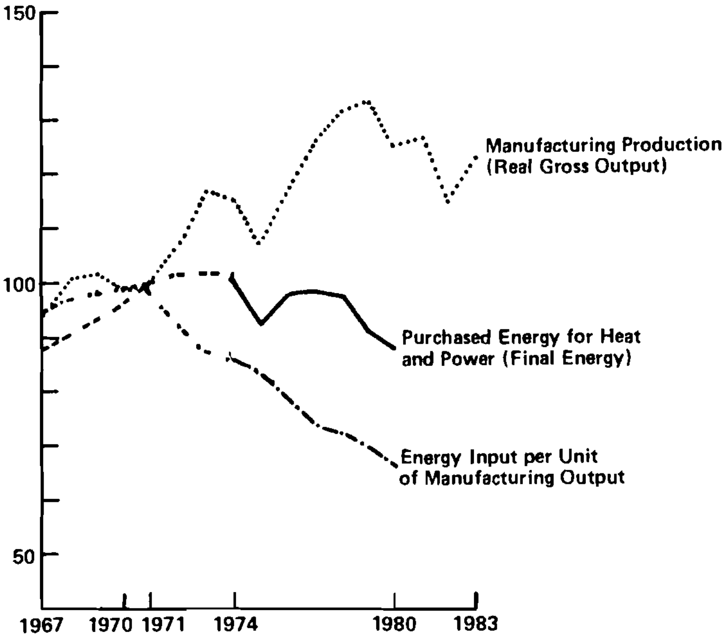

FIGURE 3. US. Manufacturing sector. The growth of production and the input of purchased energy for heat and power since 1967 (index numbers, 1971 = 100). SOURCE: Appendix Table 5. NOTE: There are no data for 1970 purchased energy for heat and power.

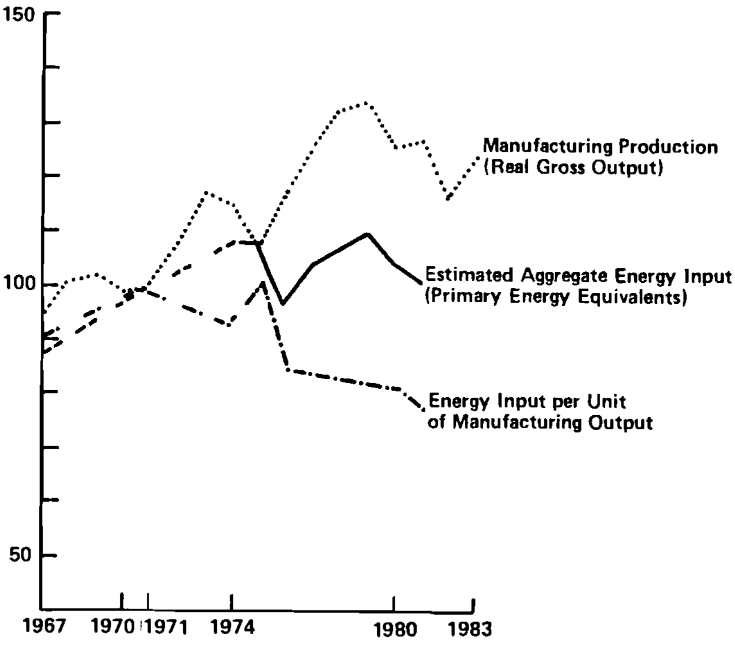

FIGURE 4. US. Manufacturing sector. The growth of production and the input of aggregate energy since 1967 (index numbers, 1971 = 100). SOURCE: Appendix Table 5. NOTE: There are no data for 1970 purchased energy for heat and power.

- Time series data for input-output industries provided by the Bureau of Labor Statistics used in the Energy Information Agency's work for the 1974-1981 period, recently presented by Werbos (Boyd et al., forthcoming).

The above summary, and our own presentations (Figures 3 and 4), lead one to suspect that the calculations for energy productivity growth do not substantially differ:

- whether the industries are studied at only the two-digit level of the SIC, or whether they are distinguished by a more refined device; or
- whether the analysis is based on constant priced gross output, or whether the more refined value added concepts are used.

Instead, the determining factors are:

- Whether the energy input comprises only purchased energy for heat and power, or the total input of all forms of energy in primary equivalents.
- Whether or not the time series are based on an unusual year, e.g., depression year, when energy productivity was exceptionally low.

Unfortunately, the selection of the energy input and the years studied are constrained by the availability of data. Similar handicaps apply also to energy productivity calculations derived from Input-Output analysis, which in turn is based on the Census, and hence excludes important energy inputs such as captive fuels for iron and steel making and hydrocarbon feedstocks for chemicals and petroleum refining.

The slower decrease of energy intensity, and hence the slower growth of energy productivity (or efficiency) in the *manufacturing* sector based on primary and more complete energy input (Figure 4), tends to agree with the likewise slower growth of energy productivity in the *industry sector*, shown in Figure 2. This similarity justifies (1) the selection of the more complete energy input in primary equivalents, and (2) the assumption that in the years for which energy input by manufacturing industries is not available, the manufacturing sector's energy productivity is likely to follow the same growth trend as that of the industry sector. This assumption is further justified by the agreement between our energy productivity compilations in the industry sector with other research in this field, as for example the energy productivity growth in the industry sector, published by DOE (US Department of Energy, Energy Information Administration, 1983, Table 32), based on research of Data Resources, Inc. (DRI). They used two measures of output:

- Energy weighted index of industrial output relative to 1981; and
- Industrial real output.

The industrial real output is defined as a measure that accounts for increases in the physical output (tons) and quality. To the extent that the quality of output per ton was increasing, energy use per unit of real output would show more energy conservation than simple energy use per ton.[3]

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[3]Real output in 18 manufacturing industries is taken from the Bureau of Labor Statistics, *Time Services Data for Input-Output Industries*, which appears in BLS Bulletin 2104 but were here taken from XOUTBLS/POUTBLS in the SAS file NATIONAL ESTIMATES. Data on the public archive tape described in the PURHAPS model for documentation, DOE/EIA-0420/1. (An updated version of basic chemical output, however, came from a BLS printout.) Real output in four manufacturing sectors comes from the Data Resources, Inc., Input-Output Service. End-use energy by manufacturing industry(weights) in 1981 is direct from the 1983 Census of Manufactures, but with purchased coke subtracted, and raw material used added (based on 1981 data taken from the 1983 *Annual Energy Outlook*). Raw materials uses are allocated to industries (including basic versus other chemicals guided by the 1981 Annual Survey of Manufactures (US Department of Energy, Energy Information Administration, 1984, p. 104).

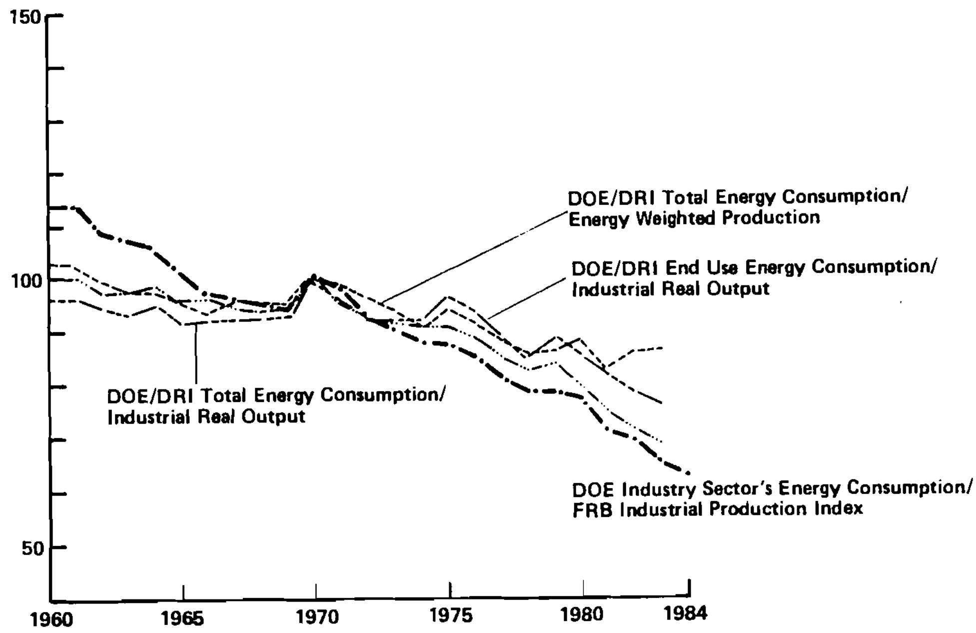

FIGURE 5. US. Industry sector. The growth of energy productivity, various compilations. SOURCE: Appendix Tables 4, 6, and 7.

The energy productivity growth rates, compiled by various sources, are summarized in Figure 5, based on Appendix Tables 3 and 4.

Figure 5 shows that the energy productivity index which we compiled from the industry sector's consumption of all forms of energy in primary equivalents, and the FRB industrial production index, agrees largely with the DOE/DRI research. The agreement persists despite these minor differences: In the long pre-1974 period, the fall in energy intensity (and hence the growth in energy productivity) was slower in the DOE/DRI research than this would appear from our data; and for the short-term recession of the early 1980s, DOE/DRI research shows a somewhat stronger fall in energy intensity than we do.

2.3. Energy Productivity Growth Abroad

Continuous growth of energy productivity in the manufacturing sector occurred in the FRG; it was particularly rapid in the period of reconstruction following World War II. In France, the decline of energy input per industry output coincided with stable or declining energy prices in the 1960s, continuing through the inflation of the 1970s (end of the data base). These trends can be seen in Figures 6 and 7 (based on Appendix Tables 8 and 9).

Interfuel substitution was one of the reasons for the growth of energy productivity in the industry sector. The displacement of coal by oil, and of coal and oil by gas, occurred in Europe somewhat later than in the US. Also, progressive electrification of industry in the US and abroad has raised the efficiency of end-use energy utilization in all industrialized countries.

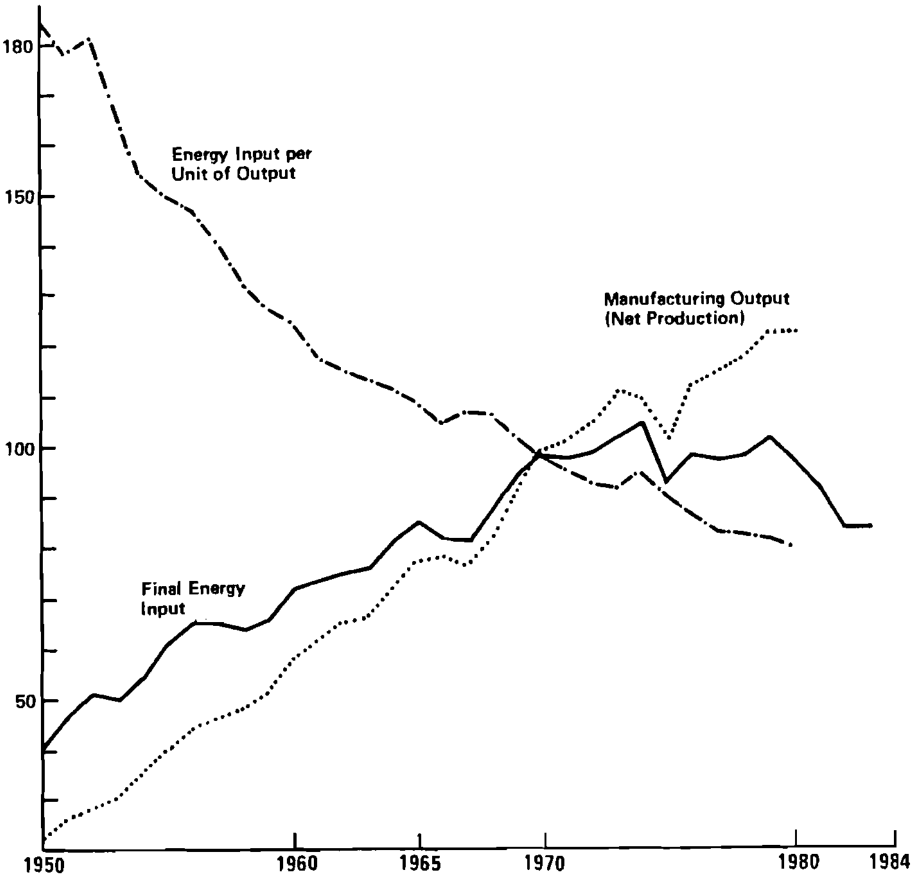

FIGURE 6. FRG. Manufacturing sector. The growth of final energy input per value added since 1950 (index numbers, 1980 = 100). SOURCE: Appendix Table 8.

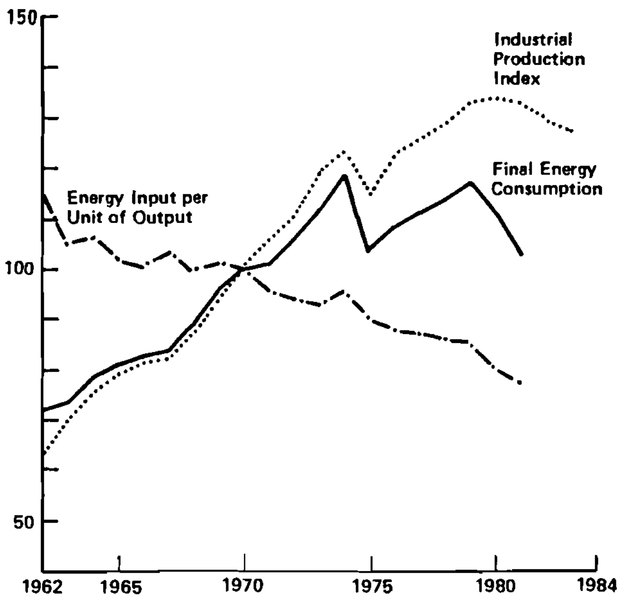

FIGURE 7. France. Industry sector. The growth of energy input per industry output since 1962 (index numbers, 1970 = 100). SOURCE: Appendix Table 9.

3. DETERMINANTS OF ENERGY PRODUCTIVITY

3.1. Role of Prices

It is commonly believed that the drop in industrial demand for energy, larger than that in other sectors, is based on price movements[4] as well as on the slow economic growth affecting all sectors. In fact, the price of total energy (fuels and electricity) purchased by the industry sector has risen faster than that purchased by the household sector. This observation not only holds true for the US, but for the FRG, France, and the UK as well (as shown in Table 1).

Total energy purchased by industry includes a higher share of petroleum products and natural gas and a relatively low fraction of electricity when compared with household energy budgets. Generally, oil and gas prices that started from a lower base have increased faster than electricity prices in the US and other countries. Table 1 shows the uneven growth of *current* prices in terms of index numbers (1970 = 100) for groups of energy commodities. In this table, the price indices for the various energy commodities are ranked in order of their growth within each of the four countries. This clearly shows that electricity prices (together with household gas and gasoline) generally occupy the lower tiers, whereas petroleum products (excluding gasoline) and natural gas appear at the top of the price range. The exception to this rule is the UK, where the price growth of natural gas – whether used by industry or in households – has continuously trailed behind those of other fuels and electricity, thanks to the UK energy policy and the abundance of natural gas from the North Sea.

The price of electricity and fuels purchased for heat and power by industry is also compiled by the US Census of Manufactures, shown as the unit cost in current dollars per million Btu of final, delivered energy and seen here in Tables 2 and 3.

On a pure Btu basis, the (average) price in the Census for purchased electricity is far higher than that for any fossil fuel.[5] The gap was widest in the pre-1973 period. For example, in 1967 the unit cost of electricity per Btu was more than nine times higher than that of natural gas and six times higher than that of residual fuel oil. After the Arab oil embargo and the ensuing first oil price explosion, the gap has narrowed. By 1981, the price of electricity per Btu was less than four times higher than that of natural gas and a little over two times higher than that of residual fuel oils (see Table 2).

The discrepancy between the growth of prices of electricity and of oil was stressed in a recent study of the International Energy Agency (IEA) (1985). A comparison of the 1973 = 100 based indices of average electricity and oil prices in the Western industrialized countries appears in Figure 8.

In the US, the cost incentive to use electricity was provided by the price of natural gas rather than that of oil, relative to purchased electricity.

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[4]This section on the growth of prices and consumption is based on Doblin (1982), which has since been expanded and updated, and Doblin (1983).

[5]However, the compilations of (average) electricity prices do not reflect the intricacies of the rate structure and long-term contracts that narrow the gap between fossil fuels and electricity on a Btu basis for large consumers. Moreover, the electricity prices have not been adjusted for the efficiency or other advantages (clean air, convenience) with which power is used. And certainly no adjustment has been made to allow for the high capital cost of power generation that is a dominant factor in the continuous preference of industrial users for purchased over self-generated electricity.

TABLE 1. US. The growth of current prices for groups of energy commodities (index numbers, 1970 = 100).

Commodity		Year						
		1973	1978	1979	1980	1981	1982	1983
USA								
Natural gas	I	122.3	413.0	523.9	732.1	904.8	1021.3	1105.1
Petroleum products	I	127.4	315.4	436.4	662.1	790.9	747.2	673.8
Petroleum products	HH	123.1	271.6	381.3	534.2	648.9	643.4	584.3
Gas utilities	HH	117.9	242.4	281.6	335.4	382.4	484.5	446.5
Electricity	I	122.1	236.7	255.2	303.7	346.4	383.9	394.8
Solid fuels	I	145.1	286.2	300.0	310.4	330.9	355.7	357.7
Electricity	HH	117.6	191.4	206.3	238.7	274.5	300.9	314.5
Gasoline		111.9	185.9	251.5	349.5	389.1	368.8	356.4
FRG								
Petroleum products	HH	168.8	227.9	406.2	465.9	545.9	577.0	530.5
Natural gas	I	110.6	223.7	225.6	291.5	393.2	464.7	458.2
Petroleum products	I	129.8	192.6	265.5	321.0	389.4	395.5	383.0
Solid Fuels	I	124.2	219.3	228.3	261.8	298.2	317.8	327.3
Solid Fuels	HH	125.2	192.8	206.2	233.5	261.7	277.4	286.3
Gasoline		123.2	156.1	170.9	202.1	245.0	236.4	230.0
Electricity	HH	117.6	165.3	169.1	176.4	197.7	216.2	223.6
Electricity	I	114.7	158.6	162.7	170.0	200.8	207.7	213.9
Gas utilities	HH	108.8	156.8	158.9	166.8	218.9	246.1	248.4
France								
Petroleum products	HH			456.8	670.2	681.7	1016.6	1101.8
Natural gas	I	131.5	296.7	320.4	474.2	620.0	760.1	836.0
Petroleum products	I	112.6	255.7	304.2	402.5	503.0	644.6	716.0
Solid fuels	HH	118.1	230.9	308.2	396.1	474.5	540.4	599.7
Gas utilities	HH	115.5	200.3	216.4	277.3	357.9	417.5	461.4
Gasoline		108.4	220.8	252.8	298.5	342.8	389.9	422.4
Electrticity	I	114.0	202.5	226.1	277.5	316.6	353.4	393.7
Electricity	HH	113.8	187.6	209.1	251.3	278.8	324.8	365.6
UK								
Petroleum products	I	139.2	564.0	710.0	993.0	1191.6	1251.2	1380.3
Petroleum products	HH	126.0	389.0	493.0	659.0	784.2	889.7	1008.3
Solid fuels	I	132.0	345.0	414.0	521.0	604.4	656.6	677.3
Electricity	HH	120.5	332.0	360.0	458.0	549.6	604.6	627.5
Solid fuels	HH	128.4	305.0	357.0	456.0	538.1	574.6	611.0
Electricity	I	114.0	303.0	335.0	413.0	479.1	524.5	524.5
Gasoline		114.0	241.0	317.0	410.0	485.0	518.0	533.6
Natural gas	I	65.0	252.0	287.0	390.0	475.8	503.1	500.9
Gas utilities	HH	115.0	206.0	213.0	249.0	313.7	390.9	438.2

I = industry; HH = households.
SOURCE: Doblin (1982); updated.

The difference between the growth of prices for electricity and other energy forms in the post-embargo period played a *direct* role in energy savings through the incentive it provided for further electrification. This shift is in itself an important means to improve the efficiency with which energy is used.

TABLE 2. US. Unit cost of selected fuels and purchased electricity consumed by all manufacturing industries, 1967, 1971, and 1974-1981.

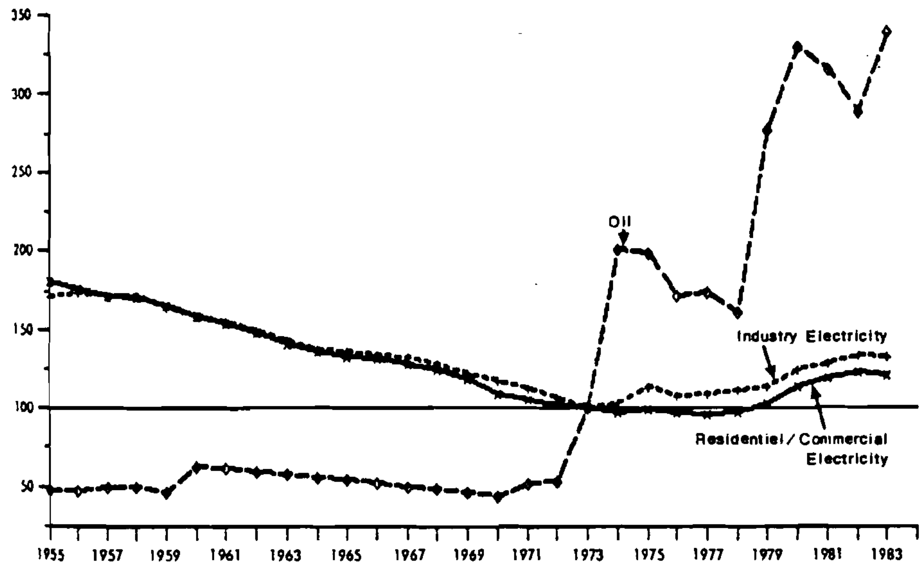
Year	Total Pur- chased	Pur- chased Elec- tricity	Natural Gas	Resi- dual Fuel Oil	Distil- late Fuel Oil	Bit.Coal, Lignite, Anthra- cite	Coke and Breeze
			Unit Cost (dollars per million Btu)				
1967	0.65	2.55	0.32	0.42	0.62	0.28	0.71
1971	0.80	2.89	0.38	0.61	0.74	0.41	0.89
1974	1.44	4.02	0.64	1.83	2.04	0.86	1.87
1975	1.93	5.06	0.95	1.93	2.24	1.12	2.58
1976	2.20	5.58	1.26	1.88	2.38	1.07	2.98
1977	2.59	6.42	1.56	2.15	2.70	1.13	3.37
1978	2.92	7.37	1.76	2.10	2.34	1.25	3.61
1979	3.32	8.15	2.07	2.76	3.81	1.33	3.78
1980	4.05	9.71	2.59	3.76	5.47	1.41	4.13
1981	4.78	11.23	3.14	4.74	6.55	1.58	4.21
			Ratio of Purchased Electricity Prices to Those of Other Energy				
1967	3.92	1.00	7.97	6.07	4.11	9.11	3.59
1971	3.61	1.00	7.67	4.74	3.91	7.05	3.25
1974	2.79	1.00	6.28	2.20	1.97	4.67	2.15
1975	2.62	1.00	5.33	2.62	2.26	4.52	1.96
1976	2.54	1.00	4.43	2.97	2.34	5.21	1.87
1977	2.48	1.00	4.12	2.99	2.38	5.68	1.91
1978	2.52	1.00	4.19	3.51	2.60	5.90	2.04
1979	2.45	1.00	3.94	2.95	2.74	6.13	2.16
1980	2.40	1.00	3.75	2.85	1.78	6.39	2.35
1981	2.35	1.00	3.58	2.37	1.71	7.11	2.67

SOURCE: US Department of Commerce, Bureau of the Census, 1982 Census of Manufactures, Fuel and Electric Energy Consumed, MC 82-S-4 (1982).

TABLE 3. US. The growth of prices for electricity and total energy purchased by the industry sector.

	Electricity	Total Energy		
	Census Year	BLS	Census	BLS
Index Numbers, 1970 = 100				
1967	88	86.5	81	86.8
1970	.	91.2	.	92.2
1971	100	100.0	100	100.0
1974	139	140.4	179	180.7
1975	175	166.5	240	212.7
1976	193	178.8	275	230.5
1977	222	200.5	323	262.3
1978	255	215.8	363	279.9
1979	282	232.6	414	354.2
1980	336	276.8	505	498.2
1981	389	315.8	596	602.7
1982	.	350.0	.	678.5
1983	.	359.9	.	651.8

SOURCES: See Tables 1 and 2.
NOTE: The growth implicit in the electricity unit cost compiled by the Census rose faster than the BLS producer prices for electricity.



Due to data availability, includes only Canada, U.S.A., Japan, Austria, Denmark, Germany, Italy, Netherlands, Norway, Portugal, Switzerland and the U.K.

FIGURE 8. International Energy Agency member countries. The growth of average electricity and oil prices in real terms.

Price-directed interfuel substitution also played a role when oil and gas were displaced by coal for electricity generation – an activity that by standards of the US classification of industrial activities (SIC) falls outside the industry sector. Moreover, faster rising prices of petroleum products as compared to those of LPG – a feedstock for petrochemicals and petroleum refining – led to a substitution by these industries of LPG for petroleum products. Finally, the shrinking volume of the petroleum refineries themselves provides an important example of consumer response to escalating prices of petroleum products, notably those used by households and motorists. Another example for the direct role of prices is seen in the migration of aluminum smelters from the US northwest across the border to Canada, in search for lower electricity prices in long-term contracts.

The largest impact on energy savings by the industry sector came from the adoption of energy saving technologies, motivated by escalating fuel prices, as for example the transition in primary paper manufacturing to recirculated waste fuels and cogeneration, as well as the primary metals' growing input of scrap, and in the 1980s the switch of cement making from "wet" to "dry" processes.

However, the historical analysis has shown that energy saving technologies were also introduced, and to a larger extent, when energy prices were generally stable or falling, and that electrification of the industry (and household) sectors were stronger when the gap between purchased electricity and that of fossil fuels was more pronounced. This leads one to conclude that in the 1974-1980 period the industry sector's decreasing energy intensity was not caused by rising oil prices alone. Reservations on the impact of energy prices on the industry sector's energy demand come also from the research of Jenne and Catell (1983) who state that

"There is still a subconscious tendency...to think that the oil crisis sparked off an improvement in energy use. This may be so in the transport and domestic energy scene where the final consumer has direct control over the energy purchases. It is not true, however, for the industrial sector of the UK..." and "All that can be said with confidence...is that fuel price rises are neither necessary nor particularly effective on their own at increasing energy efficiency".

Besides, quoting from the same authors "The role of price-induced substitution as envisaged by use of a production function is less important than has often been assumed" and "while aggregate production functions have long since lost the theoretical battle, there is a question over their use as an empirical tool."

A more mediate, less direct impact of energy prices is filtered through the structural changes in the manufacturing sector's output mix. Given the complexity of the subject, the role of energy prices in changing the output mix is not further considered, for this would be an endeavor going beyond the terms of reference of this report.

3.2. Structural Changes in Output Composition

The concept of structural changes used here differs from the broader one that refers to what is consumed, saved, and traded, and to the mix of labor, land, capital, energy, materials, and technology in production activities of the economy.

Production Volume, Percentage Structure

Structural changes, as used for this analysis, consist in changes in the composition of the nation's output mix. These are reflected in the various industries' percentage shares of total manufacturing output over a period of time, where continuous increase of shares signifies fast growth and continuous decrease means slower or no growth (Doblin, 1984a; Doblin, 1984b).

Table 4 shows that the same industries fall into the same slow or respectively fast growth pattern regardless of whether the classification is based on constant-priced (1972) sales values or value added. There is, however, on exception: based on *sales values* the share of chemicals and allied (SIC 28) in total manufacturing was still rising, though at a slower rate, from 7.13% in 1970 to 7.97% in 1980. While in terms of *value added* the shares decreased from 7.0% in 1970 to 6.3% in 1980. This discrepancy reflects the high frequency of intra-industry sales, as the chemical industry is known to be its own best customer. More important, both the *slowly* rising shares (sales values) and the decreasing shares (value added) reflect the "maturing" that came with market saturation, as for example the slowdown in the growth of petrochemicals (SIC 286), and the absolute decline of inorganic chemicals (SIC 281). The falling demand for inorganic industrial chemicals is not directly related to the energy price. It is also doubtful whether in the early 1980s the slowdown in the demand for petrochemicals was directly related to the energy price escalations. The impact of energy prices on the demand for petrochemicals produced in Western, industrialized countries, is in store for the time (if and when) oil-rich developing countries, especially those in the Gulf areas, will expand their petrochemicals industry.

The relatively low contribution to value added by the energy-intensive industries is worth noting. Table 5 shows that the five industries which in 1980 used 80% of the manufacturing sector's total energy purchased for heat and power (or 86% of the estimated aggregated energy input) provided less than one-third of the

TABLE 4. US. The changing structure of output in manufacturing industries, 1960, 1970, and 1980, measured by sales values and value added.

	Sales values at 1972 prices			Value added at 1972 prices		
	1960	1970	1980	1960	1970	1980
SIC	%	%	%	%	%	%
1. Slow growth since 1960						
20 Food & beverages	17.84	15.68	14.82	10.3	9.0	8.1
21 Tobacco	1.24	0.83	0.66	0.9	0.8	0.8
23 Apparel	3.96	3.62	3.34	3.9	3.9	3.9
24 Lumber	2.92	2.82	2.67	3.4	3.3	2.9
29 Petroleum & coal	4.01	3.96	3.90	3.1	3.1	2.4
31 Leather	1.26	0.88	0.57	1.4	1.1	0.8
32 Stone, clay & glass	3.12	2.77	2.43	3.8	3.3	2.9
33 Primary metals	8.95	8.11	6.36	8.9	7.0	6.2
37 Transport. equipment	13.19	11.94	10.83	12.8	11.6	9.7
27 Printing	4.50	4.08	4.08	6.1	5.6	5.6
	60.99	54.69	49.66	54.6	48.7	43.3
2. Slow growth since 1970						
22 Textile mill	3.19	3.53	3.34	3.1	3.5	3.2
26 Paper	3.61	3.82	3.72	3.5	3.7	3.4
28 Chemicals	5.74	7.13	7.97	5.8	7.0	6.3
30 Rubber & plastics	1.89	2.69	2.63	2.0	2.7	2.8
34 Fabricated metal prod.	6.96	7.19	6.20	7.6	7.8	7.4
39 Miscellaneous	1.46	1.53	1.41	1.8	1.7	1.7
	22.85	25.89	25.27	23.8	26.4	24.8
Groups 1 & 2	83.84	80.58	74.93	78.4	75.1	68.1
3. Fast growth since 1960						
35 N-E machinery	7.51	8.81	11.41	10.1	11.5	14.4
36 Electr. & electronic	5.45	7.26	9.32	7.2	9.0	11.9
38 Instruments	1.82	1.99	2.95	2.6	2.8	4.0
	14.78	18.06	23.68	19.9	23.3	30.3
4. No change						
25 Furniture	1.37	1.34	1.37	1.7	1.6	1.6

NOTES: Based on value added at 1972 prices, SIC 28 – chemicals and allied's share in total manufacturing output decreased between 1970 and 1980; when measured in sales values at 1972 prices, the chemicals' share still showed a slight increase. Likewise, the FRB production index of SIC 28 grew at a faster pace than total manufacturing.
SOURCE: Sales values at 1972 prices from US Commerce Department, BIA computer printouts. Value added, see national income without capital consumption adjustment by industry, in current prices in US Commerce Department, BEA, the National Income and Product Accounts of the United States 1929–1976. Statistical Tables and Survey of Current Business, No. 7, July 1982.
Data in current values converted to constant prices with deflators implicit in sales values provided by BIA.

value added (at 1972 prices). For example, the chemicals (SIC 28) and petroleum and coal processing industries (SIC 29), which together accounted for more than one-third of purchased energy for heat and power (or nearly one-half of the estimated aggregate energy input), generated less than 9% of value added. On the other hand, all fast-growing industries are in the groups that have comparatively modest energy requirements, generating high value added. Thus the groups that together consumed less than 20% of purchased energy for heat and power (and under 14% of the estimated aggregate energy input), produced over 70% of value added. The faster growth of the low energy requiring and high value added generating industries explains to some extent why total industrial output (weighted by value added) has grown so much faster than total energy input.

TABLE 5. US. Manufacturing sector. Distribution of energy input quantities and manufacturing output (value added at 1972 prices) in 1980.

	Energy Input		Manufacturing	
	Aggregate (%)	Purchased for Heat and Power (%)	Output (value added at 1972 prices) (%)	Growth Pattern
SIC Description 1				
28 Chemicals	30.657	22.883	6.3	a)
33 Primary metals	19.014	19.177	6.2	slow
29 Petroleum and coal	16.549	9.921	2.4	slow
26 Paper	7.572	10.763	3.4	b)
32 Stone, claye and glas	6.648	9.450	2.9	slow
20 Food and beverages	5.617	7.984	8.1	slow
Subtotal	86.057	80.181	29.3	
SIC Description 2				
34 Fabricated metal	2.127	3.023	7.4	b)
37 Transportation equipment	2.038	2.897	9.7	slow
35 N-E Machinery	1.979	2.813	14.4	fast
22 Textile mill	1.747	2.484	3.2	b)
36 Electricity and electronic	1.422	2.021	11.9	fast
30 Rubber and plastics	1.321	1.878	2.8	b)
24 Lumber	1.179	1.676	2.9	slow
Subtotal	11.814	16.794	52.3	
SIC Description 3				
27 Printing	0.521	0.741	5.6	slow
38 Instruments	0.474	0.673	4.0	fast
23 Apparel	0.343	0.488	3.9	slow
25 Furniture	0.278	0.395	1.6	no change
39 Miscellaneous	0.266	0.379	1.7	c)
31 Leather	0.112	0.160	0.8	slow
21 Tobacco	0.130	0.185	0.8	slow
Subtotal	2.127	3.023	18.4	
TOTAL	99.999	99.999	100.0	
1980 Aggregate energy input		trillion Btu 16,877		
1980 Purchased energy for heat and power		trillion Btu 11,873		
1980 Value added at 1972 prices		$ billion 21.4		

[a] Based on value added only, growth turned from fast to low in the 1970s.
[b] Based on value added and sales values, growth turned from fast to slow in the 1970s.
[c] Based on sales values only, growth turned from fast to slow in the 1970s.
SOURCES: Appendix Table 1 and Table 4.

Here one could speculate that the growth gap between energy input and the industry sector's output would tend to be narrower, if the weights were constituted by energy or labor input, instead of value added.

Production Growth Indices

The structural changes in the volume of output can also be measured by industrial production indices. Whereby the growth of the manufacturing sector as a whole is considered the national average, deviations from this average by individual industries mark their growth patterns: fast if the industries' growth exceeds, and slow if it lags behind that of total manufacturing. Our measurement of structural changes relies on a set of 80 production indices (FRB and quantities) based at 1970 = 100, with annual data since 1954. (See the case study on "Structural Changes in US Manufacturing Output since 1960" in Part II of this report.) Some of this information is reproduced in Figures 9-11.

Figure 9 shows that in the nearly two decades prior to the first oil price shock only a few of the energy-intensive industries had long-term slow growth. These were primary metals (because of the slowdown in steel), cement, and also, but not shown in the figures, food and kindred products. However, after the mid-1970s, the change was dramatic. The growth lag between steel and total manufacturing accentuated sharply, and nearly all of the energy-intensive industries turned to slow growth. This includes petroleum refining, aluminum (a former very fast-growth industry), and most inorganic chemicals. At the same time basic organic chemicals (that include petrochemicals) were still expanding faster than total manufacturing – but no longer at as wide a margin than earlier. This and how the recession of the early 1980s accelerated the decline of the energy-intensive industries may be seen from Figures 9, 10, and 11.

Structural Changes Abroad

The US was not the only country with ailing, slow-growth energy-intensive industries. Steel, aluminum, and cement, for example, also declined in the FRG and France, as discussed in the more detailed analysis of structural changes in Part II of this report.

The declining growth rate of Western Europe's chemical industry was the subject of a recent study of the Organisation for Economic Cooperation and Development (OECD) (1985). It emphasized the "maturing of the chemicals industry" caused by developments in petrochemicals, where

> "...substantial growth differential that petrochemicals had long enjoyed by comparison with most other industrial sectors narrowed sharply from the end of the 1960s onwards. Gradual saturation of the main markets coupled with slower general economic growth no doubt explains the very much slower growth in demand over the past ten years."

The OECD stressed that the two oil price shocks of the 1970s, and the changes they brought about in the oil price market, hastened the maturing process in the petrochemicals markets that began (in Western Europe) at the end of the 1970s. Other factors playing a role in this maturing process are the limits to substitution and in some, very limited, cases the reversal of substitution, such as the introduction of radial tires requiring a greater proportion of natural rubber. Besides petrochemicals, there was also a slowdown in the production of inorganic chemicals, for example in France, discussed in Part II. See also Appendix Table 10 for the growth of US organic and inorganic chemicals.

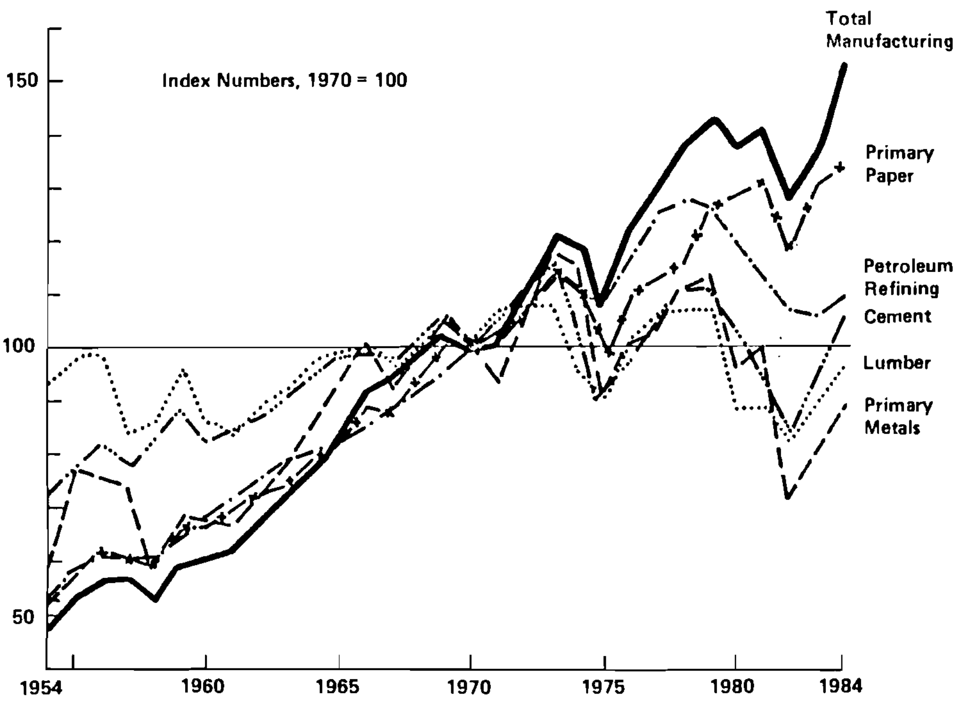


FIGURE 9. US. Energy-intensive industries (excluding chemicals), production growth.

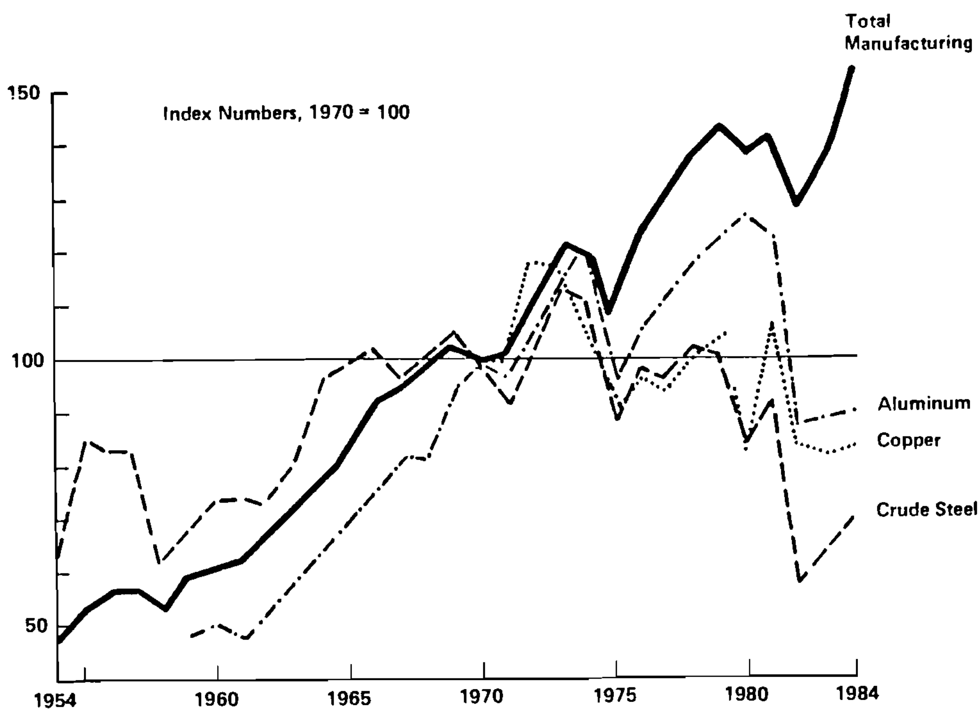


FIGURE 10. US. Primary metals, production growth.

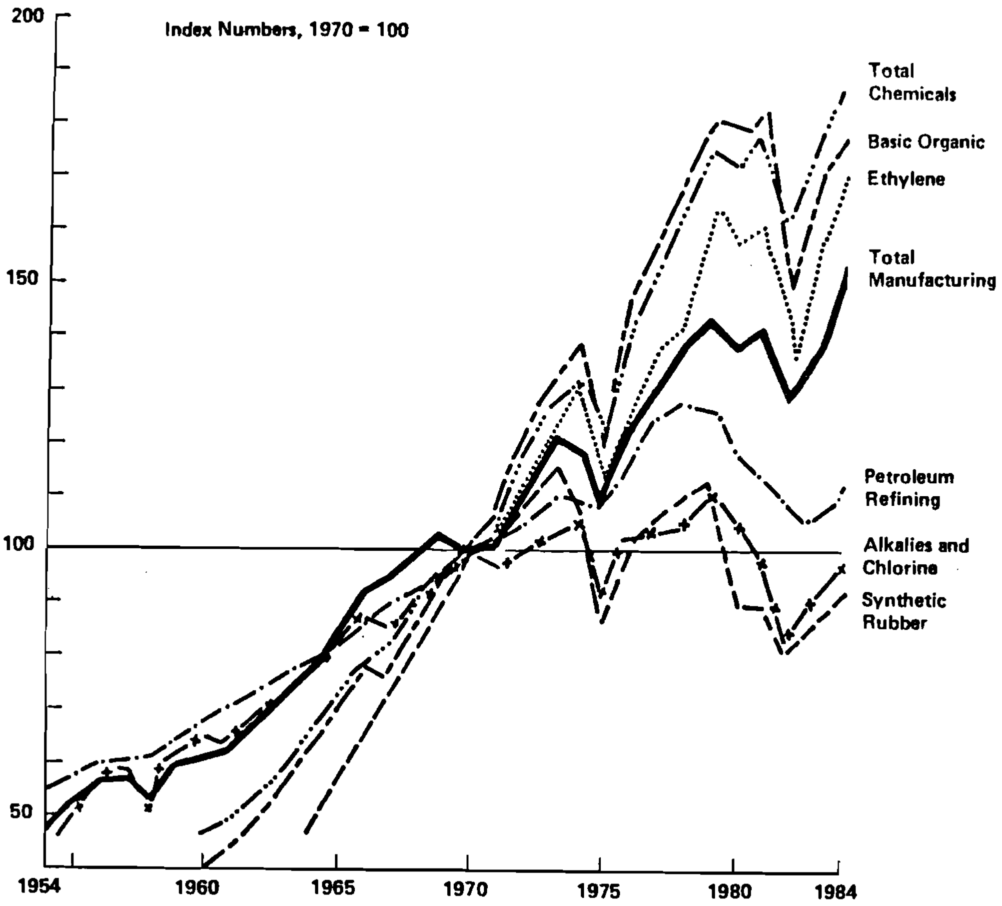


FIGURE 11. US. Chemicals, petroleum refining, production growth.

There are many reasons for an industry's stagnation, decline, or growth. Most energy-intensive industries produce primary material; these are directly affected by any changes in investments for infrastructure development. During the late 1960s and early 1970s, infrastructure operations were primarily concerned with maintenance and repair of bridges, tunnels, and roads rather than with expansion. The switch led to decreases in primary metals, stone and earth, and certain basic chemicals. Another factor contributing to the decline of energy-intensive industries is the substitution of lighter for heavier materials. Other changes in the industrial structure arose from growing affluence and the concomitant changes in tastes and habits; the migration of industries abroad (aluminum); and the penetration of domestic markets by cheaper imports, like those which exacerbated the plight of the automobile and the aging steel industries, while nearly wiping out such nonenergy-intensive industries as leather and shoes.

3.3. Technology Changes

The technology changes considered for this analysis are limited to *energy saving technologies*. These embrace all means designed to improve the efficiency with which energy is used. This ranges from process technology (e.g., the switch from open hearth to electric steel production and continuous casting) to housekeeping measures (e.g., cleaning and repairing of the flues). Some of the important changes in process technology, adopted by the energy-intensive industries, are summarized below.

Steel. In 1960, most American steel was still made by the open-hearth method (88%), while electric furnaces (8.5%) and basic oxygen (3.5%) already known were not yet applied on a large scale. Open-hearth was gradually displaced – at first mainly by basic oxygen and to a lesser extent by electric steel. By the mid 1970s, both open-hearth and basic oxygen yielded to electric steel. Its breakthrough coincided with the proliferation of mini-mills. The result was that by 1984 only 9% of steel was produced by open-hearth, 57.1% by basic oxygen, and 33.9% in electric furnaces.

Other important changes that coincided with electric steel's market penetration were the growing input of scrap and the wider adoption of continuous casting. The latter was also known already in the 1960s or earlier; but in 1975 its share in total steel production was still below 10%; while by 1984/1985 it had risen to 40%.

These various changes in technology caused sizeable reductions in the requirements of *fuels* per unit of output while at the same time raising those of *electricity*. This explains why the amounts of final, purchased energy for heat and power have increased from 11.33 million Btu per short ton of steel in 1974 to 11.46 million Btu in 1982.[6]

In terms of primary energy equivalents that include electricity losses in generation and distribution, and fuels used as raw materials (coking), the aggregate energy requirements per ton of crude steel increased even a little more, from 23.6 million Btu in 1974 to 24.1 million Btu in 1980 (see Table 6).[7]

Aluminum. A new process, said to reduce the electricity requirements from today's best of 13.3 kWh per kilogram of primary aluminum by as much as 17 to 25%, is known. This technology has not yet penetrated the market and the presently applied technology for primary aluminum smelting pre-dates the 1970s. However, a technological change not to be overlooked is the increasingly growing use of scrap. Similar to what happened in the steel industry, it began in the mid-1970s, and again similar to steel it entailed progressive use of electricity to replace fuels in the remelting of ingots and scrap.[8] Consequently, the requirements of final purchased energy for heat and power per short ton of aluminum decreased from 75.27 million Btu per short ton in 1974 to 69.07 million Btu in 1980. But with the electricity recalculated into primary energy equivalents, the decrease was only from 169.2 million Btu in 1974 to 163.5 in 1984 (see again Table 6).

Copper. Since the mid-1970s, copper like steel and aluminum favored increasingly the input of scrap. This brought about a substantial decrease in primary copper's fuel requirements and progressive input of electricity. Consequently, the input of final purchased energy for heat and power decreased from 47.30 million Btu per short ton in 1974 to 37.29 million Btu in 1980. With electricity recalculated to primary energy equivalents, the decrease was smaller, from 53.6 million Btu per ton in 1974 to 47.1 million Btu in 1980 (see again Table 6).

Chemicals and Allied. Not much is known of the implantation of new technologies to change energy productivities, except for the important housekeeping measures adopted by the industry since mid-1974. Given the diversity of the industry's

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[6]The reference years 1974 and 1980 were selected because of data availability for steel and other energy-intensive industries.

[7]Electricity in terms of primary energy equivalents represents the energy required for its production, estimated at 1 kWh = 10,236 Btu. Whereas final, purchased electricity is converted to Btu on the basis of the heat it gives out, estimated as 1 kWh = 3412 Btu.

[8]See also discussion of new, electricity-saving technology for primary aluminum smelting in US Bureau of Mines (1981).

TABLE 6. US. Selected industries growth of energy productivity, 1974 to 1980 (technology factor only).

SIC	Industry	Energy Productivity Coefficient, Based on: Purchased Energy for Heat and Power (final)		Energy Productivity Coefficient, Based on: Aggregate Energy (primary energy equivalents)		Annual Growth of Energy Productivity (compound), Based on: Purchased, Final Energy	Annual Growth of Energy Productivity (compound), Based on: Aggregate, Primary Energy Equivalents
		Million BTU per Short Ton				Percent	Percent
		1974	1980	1974	1980	1976-1980	1974-1980
331, 332	Steel (excl. waste fuels)	11.33	11.46	23.6	24.1	+0.2	+0.3
3334	Aluminum, primary	75.27	69.07	169.2	163.5	-1.45	-0.6
3331	Copper, primary	47.30	39.79	53.6	47.1	-2.9	-2.15
28	Chemicals and allied	44.30[a]	37.20[a]	81.5[a]	82.5[a]	-2.9	+0.2
2911	Petroleum refining	318.00[b]	221.30[b]	616.0[b]	563.0[b]	-6.25	-1.5
261,262, 263	Primary paper (excl. recirculated, waste fuels)	20.71	17.33	23.0	19.3	-3.0	-3.0
3241	Cement	5.96	5.10	6.8	5.9	-2.6	-2.4

[a] = 1000 BTU per dollar sales values, excluding electricity purchases by government operated plants.
[b] = million BTU per barrel refined.
SOURCE: See case studies in Part II of this report; note conversion from final to aggregate energy.

products, output aggregation in terms of quantities was not feasible. For this reason, the industry's production was measured in terms of gross output values represented by sales (shipments) at 1972 prices.

This is not a very satisfactory measure, as the aggregated sales values tend to be distorted by the frequency of intra-industry sales. But as indicated by the research in Part II of this report, the growth trends of the "gross output" and "value added" did not substantially differ.

Moreover, the energy input by product groups or subindustries is not available – hence the energy input/chemicals output ratio could only be established at the level of the chemicals industry as a whole. This indicated that in terms of final, purchased energy for heat and power the requirements per dollar sales values (1972 prices) decreased from 44,300 Btu in 1974 to 37,800 Btu in 1980. However, with purchased electricity input recalculated to primary energy equivalents, and the energy used as raw materials (feedstocks) added, the aggregate energy input increased from 81,500 Btu per dollar sales values (1972 prices) in 1974 to 82,500 Btu in 1980. This is a reflection of the growth of energy feedstocks meeting with a decline of purchased energy for heat and power, for reasons that are not quite clear. As noted by the DOE:

> "Feedstocks consumed per unit of output increased fairly steadily since the mid-1960s. The reasons for this increase in energy intensity are unclear; however, preliminary calculations suggest that trends in the mix of organic chemicals produced may be responsible" and "LPG feedstocks share increased markedly in recent years as the price of LPG declined relative to other petroleum products" (US Department of Energy, Energy Information Administration (1983).

Petroleum Refining. Similar to what happened in the chemicals industry, the major changes in applied technology consist in better housekeeping, designed to save energy. Accordingly, the input of purchased energy for heat and power dropped from 318.0 million Btu per barrel refined in 1974 to 221.3 million Btu in 1980. This is a remarkable savings, the more so as the data were not adjusted for the increased energy input required by changes in output mix, crude supply, and anti-pollution measures. However, with the addition of feedstocks, the savings become more modest. Aggregate energy input, in primary energy equivalents, fell from 616 million Btu per barrel refined in 1974 to only 563 million Btu in 1980. As in the case of chemicals, the decline of purchased energy for heat and power met with an increase of feedstocks.

Primary Paper. The transition to "self-generated" or "waste fuels" has entailed significant savings in fossil fuels. Requirements of purchased energy per short ton of primary paper (pulp, paper and board) have declined from 20,710 million Btu in 1974 to 17,330 million Btu in 1980.[9] At the same time there was an increase in the electricity requirements per unit of output – much of it met by cogeneration. Hence the purchased energy demand for heat and power, in terms of primary energy equivalents, also decreased from 23 million Btu per short ton of primary paper in 1974 to 19.3 million Btu in 1980.

Cement. There is a potential for energy savings in the transition from the "wet" to the "dry" process. The dry process, though known, did not gain much market penetration in the 1970s. And the requirements per short ton of cement decreased only from 5.96 million Btu in 1974 to 5.10 million Btu in 1980. With progressive electrification, the energy demand in terms of primary energy

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[9] The decrease has since continued but comparable data for the energy input/manufacturing output ratio are not available.

equivalents decreased somewhat less, from 6.8 million Btu in 1974 to 5.9 million Btu in 1980. The situation changed in the early 1980s, when the share of cement plants, using the dry process, increased significantly. Much of the increase came from the shutdown of "wet" plants, succumbing to the high cost of oil and gas and forced out of operation by the recession.

The analysis of the five most energy-intensive industries has shown that the impact of the technology factor on energy requirements per unit of output meant:

- Decrease of purchased energy for heat and power, especially for fossil fuels.
- Increase in purchased electricity.
- Increase of feedstocks (chemicals and petroleum refining).

4. SEPERATION OF STRUCTURE AND TECHNOLOGY EFFECTS

4.1. Analysis, 1958-1980

In the preceding section major changes in structure and technology wer reviewed, and the energy input/manufacturing output ratios were compiled for individual, energy-intensive industries. Whereas this part of the analysis is concerned with the impact of structure as distinct from technology on the energy requirements per unit of output of the manufacturing sector as a whole. Consequently, the data base differs from that used in the earlier section in these respects: it covers the pre-1974 period, and all (not selected energy-intensive) industries at the two-digit level of the SIC (not the more detailed three-digit level used elsewhere in this study). Moreover, all output is measured by sales values at 1972 prices from the IIASA data bank 1958-1980, provided by the US Department of Commerce. The values for total manufacturing from this source are the same as the "Manufacturing Real Output at 1972 Prices" shown in US Department of Energy/Energy Information Administration (1983).

The availability of purchased energy from the Census determined the selection of reference years 1958, 1967, and 1974, while 1980 was selected because it was the last year in our data bank of production values.

The variables used for the analysis are total and major energy-intensive industries' gross output 1958-1980; energy requirements in primary equivalent of purchased energy for heat and power plus energy used as raw materials for steel, petrochemicals, and petroleum refining (see Table 7).

For the decomposition into structure and technology effects, we used the following equations:

$$\frac{\sum W_t e_t}{\sum W_0 e_0} = \underbrace{\frac{\sum W_t e_0}{\sum W_0 e_t}}_{structure} \cdot \underbrace{\frac{\sum W_t e_t}{\sum W_t e_0}}_{technology\,(res.)} , \qquad (1)$$

or

$$\frac{\sum W_t e_t}{\sum W_0 e_0} = \underbrace{\frac{\sum W_t e_t}{\sum W_0 e_t}}_{structure\,(res.)} \cdot \underbrace{\frac{\sum W_0 e_t}{\sum W_0 e_0}}_{technology} , \qquad (2)$$

where W is the share of an industry in total manufacturing output at constant priced (1972) sales; e is the energy (Btu) share of an industry in total manufacturing energy input; and o and t refer to reference periods.

TABLE 7. US. Manufacturing industries. Aggregate energy input (primary equivalents) and gross output (sales at 1972 prices), 1958-1980, selected years.

SIC	Industries	1958	1967	1974	1980
	Aggregate Energy Input*		Trillion Btu		
26	Paper	892	1332	1609	1618
28	Chemicals	2939E	5463	6082	
29	Petroleum and coal products	1969E	3137	3126	
32	Stone, clay and glass	1033	1363	1532	1330
33	Primary metals	2898E	4175E	5120	4329
	Other industries	2759	4234	5255	5062
2-3	Total manufacturing	12490	17748	22116	21547
	Gross Output		Billion Dollars (1972)		
26	Paper	15	24	32	33
28	Chemicals	23	43	64	71
29	Petroleum and coal products	17	24	30	35
32	Stone, claye and glass	13	19	22	22
33	Primary metals	37	56	70	57
	Other industries	314	499	585	674
2-3	Total manufacturing	419	665	803	892

*Purchased energy for heat and power plus feedstocks.
EEstimated.

Equation (1) (Paasche type index) uses changing output structures and a constant energy input share. Equation (2) (Laspeyres type index) uses constant output structures and changing energy input shares. There are cases where the selection of the equation might bias the results. This methodological aspect was discused in some detail in Sterner (1985). However, in cases where industry growth rates and energy intensity do not change dramatically, one would not expect significant differences. We ran both equations and found not much difference in the results. They are given below.

1958-1967

1.008	×	0.89	=	0.90	Decreasing energy intensity entirely due to technology; almost no structural impact.
1.00	×	0.90	=	0.90	

1967-1974

1.065	×	0.967	=	1.03	Slightly increasing energy intensity, due to structural impact; while technology still decreases energy intensity.
1.06	×	0.97	=	1.03	

1974-1980

0.94	×	0.94	=	0.88	Equal impact on decreasing energy intensity by structural change and technology.
0.93	×	0.94	=	0.88	

A presentation of structure and technology impacts, in terms of annual growth rates, is given in Section 5, Table 12, for both energy and electricity intensity. This shows that between 1958 and 1967, the energy intensity of the manufacturing sector decreased by 1.2% per year (all growth rates are annual compound, not annual averages). Structural changes had almost no impact, and decreasing energy intensity resulted from changing technology. Between 1967 and 1974, the situation was reversed. Energy intensity of the manufacturing sector rose slightly by 0.4% – with structural changes having a stronger impact than technology. However, between 1974 and 1980 the sector's energy intensity decreased substantially by as much as 2.2% per year; and for the first time structural change was pushing down energy intensity, and this at the same rate as the technology factor.

4.2. Evaluation of Results

The analysis has shown that between 1974 and 1980, the total input of all forms of energy (aggregate energy input in terms of primary equivalents) per real gross output (sales values at 1972 prices) decreased by 2.2% yearly in the US manufacturing sector as a whole. This agrees with the findings on decreasing energy intensity compiled from the DOE total primary energy consumption and the FRB production indices, discused earlier (see again Appendix Table 1). It is also very close to the growth rates implicit in energy consumption per industrial output (2.1% annual decrease) compiled by the DOE/DRI research (see again Appendix Table 4). Moreover, the equal share of the impact of structural and technological change was also observed in the research of Hirst et al. (1983) who found that by 1981 the slowdown in economic activity accounted for about half of the apparent reduction in energy consumed by industry, and that the responsibility for the remainder was shared about equally by shifts in output mix and accelerated efficiency gains (technology factor) (Marley, 1984; Boyd, 1987).

On the other hand, in the research based on Census data for purchased energy for heat and power only, discused in Section 2.2, the share of structure effects is estimated to have been lower than that of technology. For example, in the DOE/EIA work (US Department of Energy, Energy Information Administration (1983), presented by Werbos, the impact of structure on decreasing energy intensity was estimated as about 33% for the 1974-1981 period. In the research of Samuels et al. (1984), the structure share in decreasing electricity intensity was even lower for the 1975-1976 years.

For the 1980-1984 period, the analysis would probably have shown a still stronger decrease in the energy intensity for the manufacturing sector as a whole. This argument is based on the developments in the industry sector after 1980 (see again Figure 2) and the assumption that energy productivity in industry could serve as a guide for manufacturing, for which current data are no longer available. It is also assumed that in this productivity growth, the share of structural change should have been at least as high, if not higher, than that of the technology factor. This assumption is supported by the observation that during the 1980-1984 cycle, many of the energy-intensive industries were more vulnerable to the recession and made a slower recovery than the rest of the manufacturing sector. Thus, as energy-intensive industries recede, and the industries with lower energy requirements and high value-added potential augment, the energy requirements of the sector as a whole per constant priced dollar are bound to decrease.

4.3. Energy Intensity in Developed and Developing Economies

Rising energy productivity, or conversely, decreasing energy intensity was also observed in other developed economies, as for example the FRG, France, Japan, and the UK's industry sector. Jenne and Cattell (1983) examined the change in the ratio of energy consumed to industrial production in the UK over the years 1968-1980 and found that during the 1970s structural change was a major cause of the fall in the energy/output ratio of the UK manufacturing industry. Structural changes, as defined for their analysis, relate to the demand side and manifest themselves in the shifting product mix at the micro level and in the changing industrial structure at the macro level.

In contrast to older industrial societies Sterner (1985), in his study on the energy use in Mexican industry, found an increase in energy use relative to production. This increase occurred at a time (1975-1981) when Mexican industry was provided with plentiful and inexpensive (subsidized) oil. The author decomposed the increase in energy intensity into a *structural* (output composition) and a *technological* component, concluding that "structural changes cannot explain the increased energy intensity found".

Obviously, the substitution of energy for traditional prime movers and sources of heat as well as the transition from traditional to commercial energy supplies have played a role in raising the country's energy intensity more than structural changes.

5. ROLE OF ELECTRICITY

5.1. Growth and Distribution of Electricity Purchases

Growth

Census publications of details have varied over the years: classification **changed** in 1974 for industrial chemicals; and *annual* data are lacking for the pre-1974 and post-1981 years. The analysis concentrates mainly on the 1974-1981 period for these reasons.

Compared to 1974, the peak year of the manufacturing sector's total energy purchases for heat and power, 1981 was

13.7%	below 1974 for fuels and electricity;
18.5%	below 1974 for fuels; and
7.6%	above 1974 for electricity.

Purchased electricity has traditionally grown faster than purchased fuels for heat and power. It has also continuously been preferred over self-generated electricity. See the growth of purchased fuels for heat and power, purchased electricity, and self-generated electricity minus sales in Figure 12.

As a result of the faster growth of purchased electricity, its share in total purchased energy *quantities* for heat and power has grown from 10.5% in 1958 to 13.2% in 1971 and 19.7% in 1981.

Because of the higher price per Btu of delivered electricity compared to that of fossil fuels, the share of electricity in total purchased energy *costs* (in current prices) is much higher. It rose from 44.0% in 1958 to 48.5% in 1971. But with the slower growth of electricity prices as compared to those for fossil fuels, particularly petroleum and gas, the ratio fell to 44% in the 1970s, followed by a slow lift upwards to 46.1% in 1981 (see Table 8).

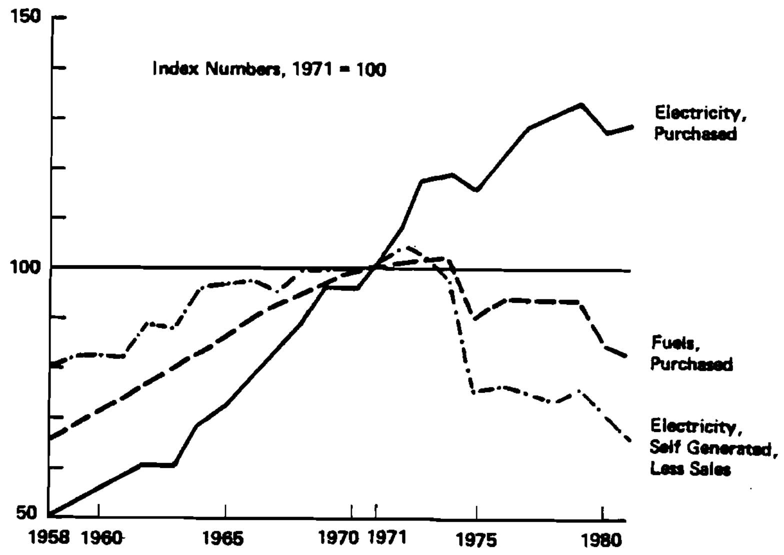

FIGURE 12. US. Manufacturing sector. The growth of purchased fuels and electricity for heat and power and self-generated electricity minus sales.

The data in Table 8 include electricity for government plants operating in SIC 281 – organic chemicals; their 1981 purchases amounted to 23.21 billion kWh (80 trillion Btu). Because of fluctuating needs that are not related to the business cycle, it is preferable to exclude government's electricity purchases. With this exclusion, the share of electricity as a percentage of the private sector's total energy purchases for heat and power increased from 9.8% in 1958 to 19.5% in 1981.

Distribution

The growth of electricity sales (kWh) to manufacturing industries at the disaggregated level of the SIC and for the years 1967, 1971, and 1974-1981 annually is shown in Appendix Table 11. For a summary by industry and year see the percentage structure in Table 9. This points out the fact that the distribution pattern is marked by high concentration at the top. Nearly one-half of 1981 electricity sales went to only two industries: SIC 33 – primary metals (25%) and SIC 28 – chemicals (20%). These industries also absorbed nearly 50% of the aggregate *energy* input (see again Appendix Table 2).

There is, however, this difference: SIC 29 – petroleum and coal products accounting for over 16% of *aggregate energy* input take a much smaller share (under 5%) of *purchased electricity*; for the remaining "high" and "medium" energy-intensive industries, the percentage shares show a much lower spread than was the case for aggregate energy input. Notwithstanding this difference, the fact remains that the fast-growth industries command only a relatively low share of electricity sales, whereas the share of slow-growth industries weighs heavily in total electricity sales. Cutbacks in these industries' production volume, because of the recession and structural changes, were the determining factor for the slowdown of electricity sales to the manufacturing sector as a whole.

TABLE 8. US. The share of electricity in total energy purchased by industry for heat and power.

Year	Quantities F+E* (trillion Btu)	E* (trillion Btu)	E/F+E (%)	Cost F+E (million US$) (current prices)	Cost E (million US$) (current prices)	E/F+E (%)
1958	8248	863	10.5	5067	2231	44.0
1962	9811	1071	10.9	6184	2823	45.7
1967	11810	1459	12.4	7692	3717	48.3
1970	.	1709	.	9425	4579	48.6
1971	13140	1739	13.2	10382	5037	48.5
1972	.	1902	.	11863	5717	48.2
1973	.	2071	.	13617	6609	48.5
1974	13394	2113	15.8	19462	8515	43.8
1975	12047	2019	16.8	23186	10284	44.3
1976	12777	2183	17.1	28139	12179	43.3
1977	12928	2263	17.5	33380	14515	43.5
1978	12931	2306	17.8	37681	16995	45.1
1979	12870	2334	18.1	42768	19063	44.6
1980	11873	2275	19.2	48206	21770	45.2
1981	11562	2273	19.7	55344	25508	46.1

*F+E = total energy; E = electricity.
NOTE: Electricity converted from kWh to Btu equivalent on the basis of 1 kWh = 3412 Btu.
SOURCES: Years 1958-1971, see Census of Manufactures MC 82-S-4, Part 1, pp. 4-7; 1972-1978 see MC 82-S-4 and earlier issues. Government operated plants included.

The importance of a few, selected industries for the growth of the sector's total electricity purchases was also emphasized by the IEA (1985) in their "bottom up" analysis of the impact of *industrial structural changes* on the electricity demand in member countries. The study stressed that "electricity demand will be much influenced by changes in the relative growth of the industries which (in the member countries) use 70% of the electricity in the manufacturing sector: iron and steel, nonferrous metals, primarily aluminum, chemical products, pulp, paper and printing, and machinery". (In America, these industries used 54% of purchased electricity in 1981.) Looking to the future, the IEA states that "although future restructuring trends are difficult to predict, it seems likely that there will be a continued slower than average growth for the iron and steel and textiles industries and faster than average growth for the chemical and metal products industries". These observations on structural changes in IEA member countries' industries tend to agree with our analysis of the US, except for chemicals where we found that the gap in growth rates between total manufacturing and total chemicals was narrowing.

5.2. Changes in Electricity Intensity

Total Manufacturing

Historically, the electricity intensity (input of purchased electricity per manufacturing output) was generally rising. This is in contrast to the *energy* intensity. However, the rising trend of *electricity* intensity finally ended in the mid-1970s, when former growth yielded to a slight decline. In terms of yearly growth rates,

TABLE 9. US. Electricity sales, distribution by industries.

SIC Purchasing Industries	Electricity Sales (quantities)(%) 1967	1974	1980	1981
28 Chemicals and allied*	22.3	20.1	20.0	20.0
33 Primary metals	25.6	26.4	24.6	25.0
29 Petroluem and coal products	4.2	4.2	4.9	4.9
26 Paper and allied products	6.0	6.6	7.5	7.8
32 Stone, clay and glass products	4.6	4.6	4.6	4.5
20 Food and kindred products	5.7	6.0	7.5	6.2
1. High energy intensive	68.4	67.9	68.9	68.4
37 Transportation equipment	5.5	4.6	4.5	4.5
35 Non-electrical machinery	3.9	4.6	4.6	4.9
22 Textile mill products	4.7	4.4	3.9	3.8
34 Fabricated metal products	3.4	4.1	3.8	3.8
36 Electric and electronic equipment	4.4	4.0	4.1	4.2
30 Rubber and plastic products	2.4	3.1	3.3	3.4
24 Lumber and wood products	1.7	2.4	2.2	2.2
2. Medium energy intensive	26.1	27.2	26.2	26.8
27 Printing and publishing	1.4	1.5	1.5	1.5
38 Instruments	0.6	0.8	0.9	0.9
23 Apparel	0.8	1.0	0.9	0.9
25 Furniture and fixtures	0.6	0.7	0.6	0.6
39 Misc. manufacturing	1.6	0.6	0.5	0.5
31 Leather and products	0.3	0.2	0.2	0.2
21 Tobacco manufactures	0.2	0.2	0.2	0.2
3. Low energy intensive	5.5	4.9	4.8	4.8
Total Electricity Purchases				
Billion KWh	427.5	616.7	659.5	665.8
Trillion Btu equivalents	1461	2104	2275	2272

NOTE: Government operated plants included.
Summarized from Appendix Table 11.

the electricity input in the manufacturing sector

increased 2.65% annual (compound) between 1958 and 1967;

and increased 2.75% annual (compound) between 1967 and 1974;

but decreased 0.49% annual (compound) between 1974 and 1980.

For the growth trends of electricity intensity, see Figure 13 which is based on total manufacturing real gross output (sales values at 1972 prices) and purchased electricity, excluding government operated plants in the chemical sector (see Appendix Tables 5 and 11).

For lack of current data, the series extend only through 1980. However, a continuation of the decrease seems likely if one can take the developments in the industry sector as a guide. This assumption is supported by the industry sector's electricity intensity, compiled from the FRB industrial production index and the DOE electricity sales to industry (see Figure 14, based on Appendix Tables 4 and 11). This shows that after 1980, the industrial sector's electricity intensity continued to decrease uninterruptedly through the 1981 recession and the subsequent recovery. Thus one may assume that electricity intensity continued its downward trend in the manufacturing sector as well.

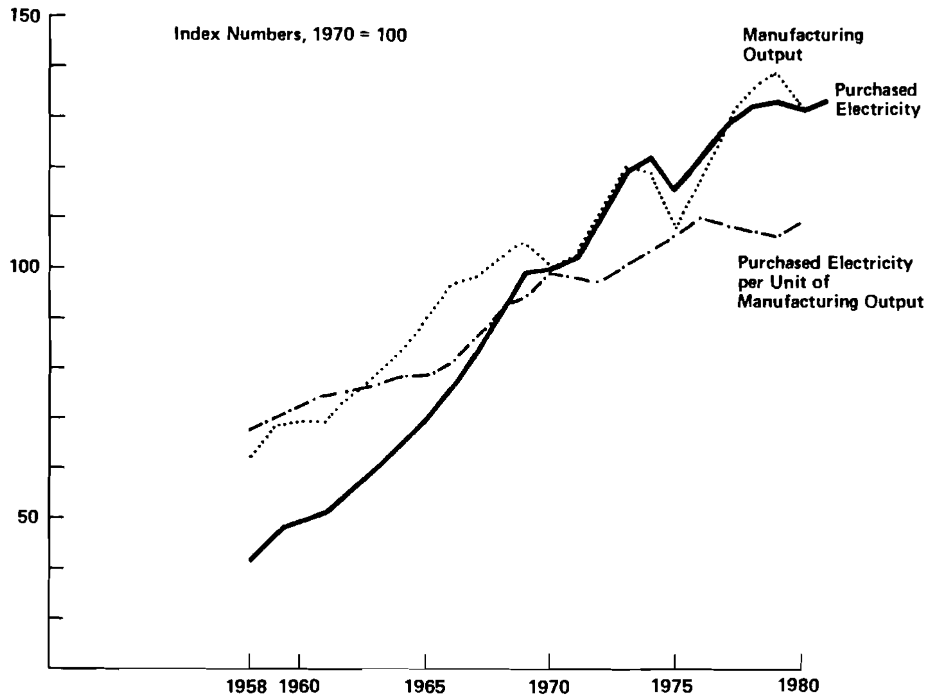

FIGURE 13. US. Manufacturing sector. The growth of electricity intensity. Purchased electricity per unit of manufacturing output.

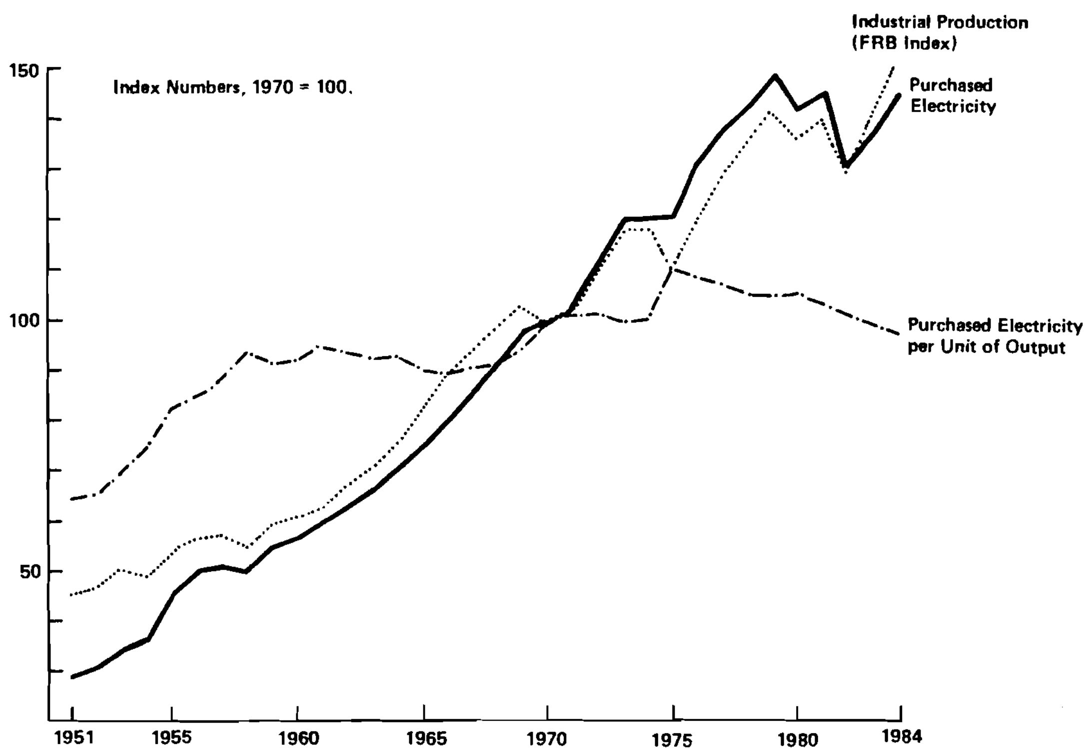

FIGURE 14. Industry sector. The growth of electricity intensity. Purchased electricity per unit of industrial output.

Selected, Electricity-Intensive Industries

Selected industries' changes in electricity intensity is measured by their electricity requirements per unit of output in 1971 (where available), 1974, and 1981 (see Table 10).

For the steel industry, this shows that the requirements of purchased electricity per short ton of steel rose 18.8% between 1971 and 1981. Per dollar sales values, the increase was 17.2% between 1971 and 1980. (Comparable sales values are not available for 1981.) Whatever the measure, Table 10 shows that the electricity intensity accelerated after 1974. This reflects the transition to electric steel, and also the proliferation of mini-mills that depend on purchased electricity as well as substitution of ore by scrap.

Scrap input also gained importance for other primary metals, such as aluminum and copper smelting. However, these industries' electricity intensity remained virtually unchanged between 1974 and 1981. New, electricity saving

TABLE 10. US. Electricity requirements per unit of output in selected industries.

Electricity Input per Short Ton Produced (kWh)

Year	Crude Steel Pur-chased	Crude Steel Total[a]	Aluminum Refining (primary) Pur-chased	Copper Refining (primary) Pur-chased	Cement Pur-chased	Cement Total[a]	Primary Paper Pur-chased	Primary Paper Total[a]
1971	415	517	.	.	106	113	512	1004
1974	422	505	13789	1025	119	125	604	1154
1975	439	505	14116	1309	126	132	601	1090
1976	427	488	13606	1238	123	128	603	1052
1977	468	524	14042	1419	123	127	603	1072
1978	452	504	13953	1335	122	126	606	1061
1979	471	529	14024	1347	115	118	560	977
1980	506	561	13868	1179	120	125	607	1007
1981	493	537	14102	1034	122	.	633	1029

Electricity Input per Dollar of Sales Values (1972 prices)(kWh)

Year	Steel (SIC 331) Purchased	Total Chemicals (SIC 28) Purchased	Industrial Chemicals Inorganic (SIC 281) Purchased	Industrial Chemicals Organic (SIC 286) Purchased	Total Manufac-turing Purchased
1971	1.831	2.02	.	.	0.746
1974	1.636	1.94	5.56	1.84	0.767
1975	1.893	2.21	5.82	2.32	0.812
1976	1.922	2.26	5.67	2.29	0.796
1977	2.074	2.14	5.32	2.16	0.763
1978	2.073	1.96	5.47	2.22	0.739
1979	2.070	1.93	5.35	2.21	0.731
1980	2.150	1.87	5.40	2.46	0.737

[a] Self-generated plus purchased less sales.
SOURCE: See case studies in Part II of this report.

technologies are known for aluminum smelting but not yet applied. See this already discused in Section 3.3.

Cement production's transition from a wet to a dry process is reflected in the requirements of purchased electricity per short ton produced, which rose by 15% between 1971 and 1981 but only by 2.5% between 1974 and 1981. Primary paper (pulp, paper and board) *purchased* electricity input per short ton produced rose strongly in the early 1970s but fell by 4.8% between 1974 and 1981. This decrease could have resulted from a number of developments such as substitution of purchased by self-generated electricity, recirculation of waste fuels and cogeneration. It could also signify that production of mechanical paper (for which electricity constitutes the major source of energy) had decreased in favor of paper produced by the chemical process – which yields a higher quality paper, demands less electricity, but creates more environmental pollution. The solution to the pollution problem lies in substitution for some or all of the problem-causing chemicals, sulfur and chlorine. This may imply a greater on-site use of electricity, since oxygen, ozone (and chlorine dioxide) are produced electrically.

For the chemicals industry as a whole (SIC 28), the electricity requirements per dollar sales values (at 1972 prices) decreased in the 1970s. This is a reflection of the structural changes underway within the industry, namely, the decline of the electricity-intensive inorganic chemicals (SIC 281), discused in the case study of the chemical industries in Part II of this report.

The remaining industries (total manufacturing minus total primary metals, paper and allied, stone, clay and glass, and chemicals) experienced nearly continuous decrease of their electricity requirements per dollar sales values by as much as 17.7% between 1971 and 1980.

An overall review of the electricity input per dollar sales values at constant prices of 1972 for selected manufacturing industries and the sector as a whole tends to indicate the following:

- Sizeable increase for the steel industry.
- Not much change for the other electricity-intensive industries (aluminum and copper refining, cement, primary paper).
- Decrease for chemicals and allied, caused to some extent by the structural change in the falling production of inorganic chemicals.
- Decrease for the remaining industries.

The analysis of the selected electricity-intensive industries tends to support the assumption that in the 1974-1980 period electrification was still progressing – though at a much slower pace than earlier. Moreover, it can be assumed that the structure effect, which tended to decrease electricity intensity, became stronger than the technology factor. This assumption is borne out by the calculations discused in Section 5.3.

5.3. Separation of Structure and Technology Effects

Purchased electricity, input quantities, and sales values at constant prices of 1972 are shown for major, electricity-intensive industries and the manufacturing sector as a whole in Table 11. The separation of structure and technology effects on the manufacturing sector's demand for purchased electricity is calculated with the Paasche and Laspeyres type indices, which were used for the separation of structure and technology on the *energy* intensity in Section 4.1.

$$\frac{\sum W_t e_t}{\sum W_0 e_0} = \underbrace{\frac{\sum W_t e_0}{\sum W_0 e_t}}_{structure} \cdot \underbrace{\frac{\sum W_t e_t}{\sum W_t e_0}}_{technology\ (res.)} , \qquad (1)$$

or

$$\frac{\sum W_t e_t}{\sum W_0 e_0} = \frac{\sum W_t e_t}{\underset{structure\ (res.)}{\sum W_0 e_t}} \cdot \frac{\sum W_0 e_t}{\underset{technology}{\sum W_0 e_0}}\ , \qquad (2)$$

TABLE 11. US. Manufacturing industries. Purchased electricity input (excluding government operated plants) and gross output (sales at 1972 prices), 1958-1980, selected years.

SIC	Industries	1958	1967	1974	1980
	Electricity Input		Billion kWh		
20	Food, beverages	15.8	24.4	36.9	41.1
22	Textiles	11.9	20.3	26.9	25.7
24	Lumber, wood products	3.4	7.3	14.8	14.7
26	Paper	12.5	25.9	40.9	49.7
28	Chemicals[a]	32.9	69.3	95.4	108.8
29	Petroleum, coal products	9.5	18.2	27.2	32.2
30	Rubber, plastics	4.8	10.2	19.0	21.7
32	Stone, clay, glass	12.1	19.6	28.9	30.5
33	Primary metals	50.7	109.5	163.3	164
34	Fabricated metal products	7.1	14.7	25.2	25.3
35	Nonelectric machinery	7.6	16.7	26.1	30.6
36	Electric machinery	7.7	19.0	24.7	27.2
37	Transport equipment	13.4	23.5	28.4	30.0
	Other industries	10.9	23.0	30.2	32.0
2-3	Total manufacturing[a]	200.3	401.6	587.9	633.7
(281)	(Government Plants)	(52.7)	(26.1)	(28.8)	(24.4)
	Gross Input	Billion Dollars (1972)			
20	Food, beverages	78	103	118	132
22	Textiles	14	22	26	30
24	Lumber, wood products	13	18	21	24
26	Paper	15	24	32	33
28	Chemicals	23	43	64	71
29	Petroleum	17	24	30	35
30	Rubber, plastics	7	14	22	23
32	Stone, clay, glass	13	19	22	22
33	Primary metals	37	56	70	57
34	Fabricated metal products	30	50	54	55
35	Nonelectric machinery	32	58	80	102
36	Electric machinery	21	47	58	83
37	Transport equipment	52	87	96	97
	Other industries	67	100	110	126
2-3	Total manufacturing	419	665	803	892

[a]Excludes government-operated plants in SIC 281.

where W is the output share of an industry in total manufacturing; e is the electricity input share of an industry in total manufacturing; and o and t refer to reference periods.

Again, both equations were run with almost identical results. They are presented below in the form of annually compounded growth rates. A similar presentation is made on the *energy* intensity, repeated from Section 4.1 but now also expressed in terms of growth rates to facilitate comparison (see Table 12). This shows that between 1974 and 1980, the *electricity* intensity of the manufacturing sector decreased for the first time by one-half of a percent annually. This overall decline was caused by the downward push of the structure effect (- 1.2%) being stronger than the technology factor's upward push (+ 0.7%). Still the decline of the electricity intensity (- 0.5%) was much lower than the decline of energy intensity (- 2.2%) over the same period.

5.4. Comparison with other Research

The decreasing electricity intensity of the US industry sector was also observed by Marlay (1985). Marlay estimates that for mining and manufacturing combined, "sectoral shifts accounted for 67% of the (electricity intensity) reduction for the period **1972-1984**." Likewise, decreasing electricity intensity in UK manufacturing was also observed by Hankinson and Rhys (1983). Their study gives an analysis of recent trends in industrial output and electricity consumption. Based on the examination of changes in the manufacturing structure, they expect these changes to have a "significant" effect on overall consumption of electricity additional to any effect of changes in the overall level of industrial output.

TABLE 12. The impact of structure and technology changes on the energy and electricity intensity of the US manufacturing sector.

Years	Aggregate Primary *Energy Input*[a] per *Real Gross Output*[b]	Annual Compound Growth Rates (%)	
		Impact on Energy Intensity by Changes in:	
		Structure	Technology
1958-1967	-1.2	0	-1.2
1967-1974	+0.4	+0.8	-0.4
1974-1980	-2.2	-1.1	-1.1
	Electricity[c] Input per *Real Gross Output*[b]	Impact on Electricity Intensity by changes in:	
		Structure	Technology
1958-1967	+2.7	+0.2	+2.5
1967-1974	+2.8	+0.6	+2.2
1974-1980	-0.5	-1.2	+0.7

[a]Purchased energy for heat and power, plus energy used as raw materials, in terms of primary energy equivalents.

[b]Sales values at 1972 prices.

[c]Purchased electricity.

NOTE: + = intensity increases; - = intensity decreases.

6. ENERGY SAVINGS THROUGH IMPORT PENETRATION OF DOMESTIC MARKETS

An important part of the decrease of energy and electricity intensity in the manufacturing sector comes from import substitution. The question is how much less energy and electricity are used because of the imports of energy-intensive products from abroad. To avoid any misunderstanding on the direct role of energy prices discused in Section 3.1, it should be stated that possibly lower energy prices abroad were not the reason for the inundation of domestic markets by the energy-intensive products. The analysis is limited to the energy content of "final" goods, excluding the energy input required for their intermediate production. Since trade and production tend to fluctuate annually, the analysis was carried out over a number of years. But a full set of annual data covering the 1970-1984 period could not be established, owing to gaps in import, production, and "energy content" data. For these and other reasons, the estimated energy savings serve at best to indicate the general trend and approximate levels of energy savings through imports.

6.1. Share of Imports in Domestic Production

The share of imports in domestic *production* (not supply) are shown in Table 13. These coefficients were compiled for selected energy-intensive industries' production and import *quantities*, except for basic chemicals where production and import *values* were used. For an evaluation of the results it should be kept in mind that import shares based on quantitative data tend to be higher than those based on production and import values, because of the pricing of domestic production (higher) and imports (lower).

In most of the energy-intensive industries, import penetration has grown in the 1970s. This is true particularly for steel mill products, where the share of imports in domestic production rose from 4.8% in 1960 to 14.8% in 1970 and to around 20% by the end of the decade. In the 1980s, further inroads were made as steel mill products' imports soared to as high as 35.5% of domestic production in 1984.

For primary aluminum, the share of imports in domestic production rose from 14% in 1971 to nearly 19% in 1982 (end of our data base); for basic copper and products, the import share rose from 1.5% to 4.1% over the same period. In the early 1980s, the dollar's recovery from weaknesses favored imports over domestic production.

Progressive import substitution did not, however, occur in all energy-intensive industries. The share of imports in domestic production of petroleum refining, for instance, fell from a record 21.7% in 1973 to a low of 11.3% in 1980, returning to 14.4% in 1984. For primary paper, the share of imports in domestic production tumbled from 47.4% in 1965 to 42.4% in 1970, and further during the decade to 34.2% in 1981.

Cement's share of imports in domestic production rose from 7.4% in 1974 (earlier data presently not available) to 10.9% in 1979, but it has since fallen to 4.5% in 1982 (latest available year).

For inorganic basic industrial chemicals, the import share did rise from 8.1% in 1972 to 14.5% in 1982 (beginning and end years of our data base). This is somewhat similar to what happened in the steel industry: import substitution coinciding

TABLE 13. US. The share of imports in domestic production of selected, energy intensive industries (percentage).

Year	Steel Mill Products Tonnages	Primary Aluminum Tonnages	Primary Copper Tonnages	Basic Chemicals Inorganic (values at current prices)	Basic Chemicals Organic (values at current prices)	Nitrogen Fertilizers Values at Current Prices	Nitrogen Fertilizers Tonnages	Petroleum Refining Barrels	Cement Tonnages	Primary Paper (quantities)
1960	4.8							9.1		
1961								9.8		
1965	11.2							12.3		47.4
1970	14.8							17.4	3.4	42.3
1971	17.9	14.13	10.3					18.0	3.9	
1972	16.6	15.99	10.3	8.1	4.6			19.3	5.9	
1973	12.4	11.22	10.9	8.5	4.7	8.0	9.8	21.7	7.9	
1974	14.6	10.36	19.0	6.9	5.7	8.2	10.6	19.6	7.0	40.9
1975	15.0	11.80	10.2	9.8	5.0	9.9	12.8	14.4	5.4	34.6
1976	16.0	13.40	24.9	12.2	5.2	9.9	11.5	13.8	4.2	36.6
1977	21.2	14.83	26.1	12.0	5.5	9.2	17.1	13.8	5.0	37.6
1978	21.6	15.75	28.5	13.6	6.1	13.0	17.8	12.6	7.7	42.0
1979	17.4	11.36	14.2	12.6	5.9	14.9	19.5	12.3	10.9	40.6
1980	18.5	11.32	37.8	14.1	6.0	13.5	20.8	11.3	6.9	36.1
1981	22.5	14.36	23.0	14.5	5.9	13.5	18.8	11.4	5.5	34.2
1982	27.1	18.82	23.2			12.9	21.8	12.1	4.5	
1983	25.3					.	26.9	13.1		
1984	35.5					.	38.0	14.4		

NOTE: Percentages of import shares compiled in values at current prices, derived from BLS Trade Monitoring System.
SOURCES: See Part II, case studies.

with cutbacks in domestic production of an old and energy-intensive industry. Inorganic chemicals are thus in contrast to the organic chemicals, a *newer* energy-intensive industry that includes petrochemicals. The organic chemicals import share was fairly low in 1972 (4.6%) and rose to no more than 6% at its 1980 peak, followed by 5.9% in 1982. The import share may have risen to 8.8% in 1983 according to Little (1981).

6.2. Estimated Energy and Electricity Savings

As stated above, the energy savings relate only to the final products as imported, excluding energy input of intermediate products. The estimates are compiled from the *product* imports and the energy coefficients (energy input per manufacturing output) established in the case studies in Part II of this report for the *industries* producing these articles. The savings are compiled for: (a) aggregate energy input, which includes all forms of energy consumption, namely purchased energy for heat and power plus energy raw materials; (b) purchased energy (fuels and electricity) for heat and power; and (c) purchased electricity. All savings are given in final, delivered energy (not re-computed into primary energy equivalents). For steel mill, aluminum and copper basic products, petroleum refining, primary paper, and nitrogenous fertilizers, the coefficients and the imports are based on *quantities*; for basic chemicals, the coefficients and imports relate to sales values at constant 1980 prices.

Annual energy savings are shown in Appendix Table 12. This indicates that, consistent with the data in Table 13, the energy savings tended to increase through import penetration for all of the selected energy-intensive industries, with the exception of petroleum refining and primary paper.

An overview of the 1980 energy and electricity savings is given in Table 14, summarized from Appendix Table 12. This shows that in terms of aggregate energy input, the greatest savings through imports originated with petroleum products, followed by steel mill products, organic basic chemicals, and nitrogenous fertilizers. In terms of purchased energy for heat and power, the greatest savings came from steel mill products, followed by primary paper (although both imports and coefficients of purchased energy input had markedly decreased during the 1970s), and petroleum products. For purchased electricity, the greatest savings came from primary paper, followed by primary aluminum and steel mill products – with only relatively small savings for petroleum products and basic chemicals (organic and inorganic).

6.3. Comparison with other Research

A comparison with the energy input of the manufacturing sector as a whole indicated that energy savings through imports amounted to no more than 5-6% in 1980 (see again Table 14). But it stands to reason that in the years following 1980 and through 1984, the share of energy savings in the manufacturing sector's total energy input have increased – due to the fact that the manufacturing sector's total energy input decreased, while import substitution increased.

Had it been possible to estimate the energy savings deriving from imports of *all* manufactured goods, and including the intermediate products, the estimates for 1980 (and subsequent years) would have obtained far higher values. This is evident from the research on the electricity content (final and intermediate) of traded merchandise of *all* sectors of the US economy, performed by the INFORUM (Inter-Industry Forecasting Project of the University of Maryland). The results of their study, as published by the Edison Electric Institute (Electricity Trade Balance, 1986), are *inter alia*

TABLE 14. US. Energy savings through imports, 1980.

Importing Industries	Aggregate Energy Input[a] (trillion Btu)	Purchased Energy for Heat and Power (trillion Btu)	Purchased Electricity (billion KWh)
Steel mill products	320.9	191.4	7.8
Primary aluminum	.	45.8	9.2
Basic copper products	.	24.1	0.6
Basic chemicals			
Inorganic	.	44.6	2.1
Organic	123.5	44.7	1.1
Nitrogeneous fertilizers	77.3	34.8	0.5
Petroleum products	336.0	133.0	3.4
Cement	.	27.0	0.6
Primary paper	.	173.0	11.0
Total selected industries	857.7	718.4	36.3
Manufacturing sector Energy input	16,877.0	11,873.0	659.5
Importing industries' energy savings as percent of manufacturing sector's energy input	5.08	6.05	5.5

[a]Purchased energy for heat and power plus feedstocks.
NOTE: The energy savings exclude energy input requirements of intermediate products and are in terms of final, delivered energy.
SOURCE: Appendix Table 12.

1985 Electricity Content	Billion kWh
Exported goods	127
Imported goods	254
Net imports	127

Considering that 1985 electricity generation (net) by the utilities serving *all* sectors of the economy amounted to 2409 billion kWh, the share of the electricity content of *all* imported goods (254 billion kWh) amounts to roughly 10.5% of total purchased electricity.

7. CONCLUSION

In the post-World War II period, technological change has been the driving force behind US energy productivity improvements (decreases in energy use per unit of output) in manufacturing. However, this study has shown that structural change was the important force behind the *acceleration* of energy productivity improvements in the post-embargo period, after being a neutral or slightly negative force in earlier years. On the other hand, the study also showed that technology has been biased toward *greater use* of *electricity* per unit of output in manufacturing, although this effect appears to have weakened in recent years. As in the case of total energy, structural change was the dominant force in the overall reduction of electricity use per unit of output in the post-embargo period. Import penetration was found to have been an important factor in reducing US manufacturing energy and electricity requirements in the decade of the 1970s and there is additional evidence to suggest that this effect was even larger in the early 1980s.

The recently accelerated growth of energy productivity, or, conversely, accelerated decrease of energy intensity, is a sign of the US having reached a mature and late stage of industrialization. A similar development of decreasing energy and lately also decreasing electricity intensity was observed in the UK, largely motivated by structural change in output mix. Thus the industrially aging societies are in contrast to the industry sectors of the developing countries, as seen in the example of Mexico, where it was found that substitution of energy for traditional prime movers and increasing use of commercial energy were the principal force behind the rising energy intensity, respectively decreasing energy productivity.

Finally, it is believed that this analysis, although based on historical data, is important for a better understanding of energy demand by industry and provides new insights for energy demand modeling. Hence, the impact of a declining oil price need not necessarily increase energy and electricity intensity – although total energy and electricity demand by the industry sector may be lifted somewhat through future economic growth. This suggests that GNP and energy demand will continue to go their separate ways as the energy-intensive industries fail to recapture their former relative importance in the US and other developed countries' economies.

This decoupling of energy demand and economic growth is also implicit in other ongoing IIASA research within the scope of the Technology, Economy and Society (TES) program.

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Appendix 1
Energy Input Methodology

Final, Delivered Energy. Fuels and electricity were converted to equivalents of British Thermal Units (Btu) on the basis of their ***average heat content***. (A Btu is the quantity of heat required to raise the temperature of one pound of water by one degree Fahrenheit.)

The measure is used since 1976 by the quinquennial Census and the former Annual Survey of Manufactures. The average conversion rates compiled by the Census for 1981 are shown below.

Conversion to Btu (1981)

Kind of Energy		Btu (1000)
Electric energy	1000 kWh	3412
Coal	short tons	26194
Coke	do	25993
Fuel oil		
Distillate	barrels (42 gal.)	5824
Residual	do	6285
Natural gas	1000 cu.ft.	1020
Liquefied petroleum gases	1000 lbs.	20989
Other fuels	dollars	259

Note: For costs of "fuels not specified by kind", conversion factors for 1981 were developed for each two-digit SIC group, based on the relationship of total cost of fuels to the total Btu equivalents for those groups, as published in M80(AS)-4.1, Fuels and Electric Energy Consumed, 1980 Annual Survey of Manufactures.

SOURCE: 1982 Census of Manufactures MC 82-S-4 (Part 1).

Primary Energy Equivalents. In terms of primary energy requirements, purchased electricity is converted to Btu by the average fuel used in electric utilities per kWh produced, and not the heat content obtainable from it.

The heat rate (average fuel used per kWh produced) was estimated as 10,500 Btu per *net* kWh for 1982, by the Edison Electric Institute.[1] Whereas the heat content was estimated as 3412 Btu per kWh by the Census for 1981 (1982 data not available).

In our compilations, we have reconverted the Btu equivalents of purchased electricity to primary equivalents through multiplication by a factor of 3. This "back to the powerhouse" measure may involve a slight under-estimation especially for recent years.

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[1]The losses in conversion from fuels to electricity are substantial and increasing. For the utilities in the United States, the Edison Electric Institute estimates the average Btu per net kWh as having risen from 10,495 to 10,517 in 1982. See Edison Electric Institute, Economics and Finance Groups, Statistics Department. *Analysis of Fuel for Electric Generation.* August 1983.

For reconversion of delivered, solid fuels, natural gas and petroleum products to primary energy equivalents, we did not make any adjustments, because of the small gap between primary and final energy. Thus our concept of "primary energy equivalent is close to the *gross energy input* as defined by John G. Myers.[2]

An example for the compilation in primary energy equivalents are the end-use energy consumption by the industry (and other) sectors published by the Department of Energy (DOE) in their Monthly Energy Review.

In our case studies in Part II, the energy productivity coefficients were compiled in terms of final, delivered energy, to facilitate comparison with other sources. For the Overall Review in Part I, the coefficients were compiled in both *delivered* and estimated *primary* energy equivalents of aggregate energy input.

Aggregate Energy Input

The aggregate energy input of the manufacturing sector consists of purchased energy (fuels and electricity) for heat and power used by all manufacturers and the energy raw materials or feedstock (the terms are used alternately) required for petrochemical, petroleum refining and steel production. Frequently, US energy productivity analysis is only based on the time series from the Census of Manufactures for purchased energy for heat and power. However, this energy input followed a different growth trend from that of feedstocks, as for example in petroleum refining and petrochemicals where the input of purchased energy for heat and power went down, and feedstocks went up. Hence the omission of feedstocks (estimated as about one third of total) from aggregate energy used by the manufacturing sector as a whole tends to bias the findings on falling energy demand and rising energy productivity. A compelling reason for the omission is the data gap on feedstock. Time series are not available from the Census except for partial data compiled at five year intervals and published as part of other raw materials' input, last collected for 1982.[3] To make up for this deficiency, a supplementary survey was taken by the Census for the Department of Energy (DOE). Only two issues of what was to become an annual survey were published with data for 1980; 1979 and some for 1978.[4] The Census survey of energy raw materials includes *purchased* and *nonpurchased* hydrocarbons (gases, gas liquids, petroleum liquids) and nonpurchased, or captive fuels (coke and coke screenings, coke oven and blast furnace gas and other by-product fuels produced and consumed at the same establishment). This raises the question of which of the hydrocarbons and fuels should be aggregated without double counting? While the Census includes all surveyed materials, industry sources favor a selection. The difference between the Census and industry compilations is particularly acute for the petroleum refining industry; although it needs to be noted that energy raw materials do not include crude throughput.

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[2] John G. Myers, *Saving Energy in Manufacturing*, Ballinger Publishing, Cambridge, Mass., 1978.

[3] See US Department of Commerce Bureau of the Census. Industry Series Preliminary Report, MC 82-I-33A-1(P) Table 4; and Industry Series MC 77-I-33A, Table 7 (with data for 1977 and 1972).

[4] US Department of Commerce. Bureau of Census. 1979 Annual Survey of Manufacturers. Hydrocarbon, Coal and Coke Materials Consumed M 79 (AS)-4.3. 1980 Annual Survey of Manufactures. Hydrocarbon, Coal and Coke Materials Consumed M 80 (AS)-4.3.

A comparison of the 1979 feedstocks by sources of compilation shows:

	Unit	Census and Survey*	Estimates Based on Industry Sources
Petroleum refining	Quad.Btu	5.24	1.65
Petrochemicals	Quad.Btu	2.38	2.55
Blast furnaces, steel mills	Quad.Btu	1.41	0.78

*See Chart 1 in 1980 Annual Survey of Manufacturers 1980 (AS)-4.3

After discussion with representatives from the chemicals, petroleum and steel industries, we have estimated the time series on the basis of data coming from industry sources.

At the two digit level of the SIC, the 1979 aggregate energy input (purchased energy for heat and power plus feedstock) would amount to:

	Unit	Census and Survey	Estimates Based on Industry Sources
SIC 29 Petroleum and coal products	Quad.Btu	6.49	2.90
SIC 28 Chemicals	Quad.Btu	5.28	5.45
SIC 33 Primary metals	Quad.Btu	4.10	3.47

Accordingly, we estimated the 1979 aggregate energy input for the manufacturing sector as a whole as 17.9 quadrillion Btu, including 12.9 purchased for heat and power, and 5.0 for energy raw materials; the estimates for 1980 are respectively 16.9 (aggregate), 11.9 (heat and power), and 5.0 feedstocks, For details and time series see Appendix Table 1.

The discrepancy between the industry based estimates and those from the Census and Survey for the petroleum refining industry were explained by A.G. Meyer, Shell Oil, Houston:

> "The Census of Manufactures Survey is a manufacturing site specific survey and all energy demand is reported under the dominant SIC industry at that site. Therefore, energy demand for chemical manufacture at a refining location would be included and reported as refining energy demand. This results in major overstatement of energy demand for the refining industry. One should use either the API or DOE surveys as opposed to the Census of Manufactures Survey to obtain energy demand for a specific industry" (letter of 1 August 1985).

Appendix 2

List of Tables

APPENDIX TABLE 1. US. Structure of aggregate energy input (final, delivered), selected years (In trillion Btu).

NUMBER-INDUSTRY	ENERGY FOR HEAT & POWER (1967)	ENERGY RAW MATERIALS (1967)	AGGRT ENERGY INPUT (1967)	ENERGY FOR HEAT & POWER (1971)	ENERGY RAW MATERIALS (1971)	AGGRT ENERGY INPUT (1971)	ENERGY FOR HEAT & POWER (1979)	ENERGY RAW MATERIALS (1979)	AGGRT ENERGY INPUT (1979)	ENERGY FOR HEAT & POWER (1980)	ENERGY RAW MATERIALS (1980)	AGGRT ENERGY INPUT (1980)
* SIC/DESCRIPTION 1												
28-CHEMICALS	2460	1032	3492	2779	1405	4184	2896	2551	5447	2717	2457	5174
33-PRIMARY METALS	2422	1005	3427	2449	1303	3752	2685	785	3470	2277	932	3209
29-PETROLEUM & COAL	1394	982	2376	1593	1055	2648	1245	1649	2894	1178	1615	2793
26-PAPER	1156	0	1156	1316	0	1316	1300	0	1300	1278	0	1278
32-STONE,CLAY & GLASS	1229	0	1229	1306	0	1306	1266	0	1266	1122	0	1122
20-FOOD & BEVERAGES	900	0	900	1031	0	1031	949	0	949	948	0	948
** Subtotal **	9561	3019	12580	10474	3763	14237	10341	4985	15326	9520	5004	14524
* SIC/DESCRIPTION 2												
37-TRANSPORT. EQUIPMENT	365	0	365	388	0	388	385	0	385	344	0	344
35-N-E MACHINERY	312	0	312	367	0	367	352	0	352	334	0	334
22-TEXTILE MILL	315	0	315	364	0	364	315	0	315	295	0	295
34-FABRICATED METAL	290	0	290	352	0	352	386	0	386	359	0	359
36-ELECTR. & ELECTRONIC	235	0	235	274	0	274	250	0	250	240	0	240
30-RUBBER & PLASTICS	183	0	183	231	0	231	249	0	249	223	0	223
24-LUMBER	188	0	188	277	0	277	223	0	223	199	0	199
** Subtotal **	1888	0	1888	2253	0	2253	2160	0	2160	1994	0	1994
* SIC/DESCRIPTION 3												
27-PRINTING	66	0	66	104	0	104	90	0	90	88	0	88
38-INSTRUMENTS	53	0	53	69	0	69	80	0	80	80	0	80
23-APPAREL	47	0	47	67	0	67	61	0	61	58	0	58
25-FURNITURE	46	0	46	62	0	62	51	0	51	47	0	47
39-MISCELLANEOUS	89	0	89	61	0	61	46	0	46	45	0	45
31-LEATHER	33	0	33	34	0	34	20	0	20	19	0	19
21-TOBACCO	19	0	19	19	0	19	21	0	21	22	0	22
** Subtotal **	353	0	353	416	0	416	369	0	369	359	0	359
** Total **	11802	3019	14821	13143	3763	16906	12870	4985	17855	11873	5004	16877

[a]Excludes residue fuels and self-generated hydropower, 1050 trillion BTU.

SOURCES: Purchased energy for heat and power, see US Census of Manufacturers and Annual Surveys M82(AS)-4.1 and earlier issues. Energy use as raw materials is compiled as the difference between aggregate energy input from industry sources and Census data on purchased energy for heat and power.

APPENDIX TABLE 2. US. Structure of aggregate energy input (percentages), selected years.

NUMBER-INDUSTRY	PERCENT PURCHASED ENERGY FOR HEAT & POWER (1967)	PERCENT AGGREGATE ENERGY INPUT (1967)	PERCENT PURCHASED ENERGY FOR HEAT & POWER (1971)	PERCENT AGGREGATE ENERGY INPUT (1971)	PERCENT PURCHASED ENERGY FOR HEAT & POWER (1979)	PERCENT AGGREGATE ENERGY INPUT (1979)	PERCENT PURCHASED ENERGY FOR HEAT & POWER (1980)	PERCENT AGGREGATE ENERGY INPUT (1980)
* SIC/DESCRIPTION 1								
28-CHEMICALS	20.843	23.561	21.144	24.748	22.501	30.506	22.883	30.657
33-PRIMARY METALS	20.521	23.122	18.633	22.193	20.862	19.434	19.177	19.014
29-PETROLEUM & COAL	11.011	16.031	12.120	15.663	9.673	16.208	9.921	16.549
26-PAPER	9.794	7.799	10.012	7.784	10.101	7.280	10.763	7.572
32-STONE,CLAY & GLASS	10.413	8.292	9.936	7.725	9.836	7.090	9.450	6.648
20-FOOD & BEVERAGES	7.625	6.072	7.844	6.098	7.373	5.315	7.984	5.617
** Subtotal **	81.011	84.879	79.692	84.212	80.349	85.835	80.181	86.057
* SIC/DESCRIPTION 2								
37-TRANSPORT. EQUIPMENT	3.092	2.462	2.952	2.295	2.991	2.156	2.897	2.038
35-N-E MACHINERY	2.643	2.105	2.792	2.170	2.735	1.971	2.813	1.979
22-TEXTILE MILL	2.669	2.125	2.769	2.153	2.447	1.764	2.484	1.747
34-FABRICATED METAL	2.457	1.956	2.678	2.082	2.999	2.161	3.023	2.127
36-ELECTR. & ELECTRONIC	1.991	1.585	2.084	1.620	1.942	1.400	2.021	1.422
30-RUBBER & PLASTICS	1.550	1.234	1.757	1.366	1.934	1.394	1.878	1.321
24-LUMBER	1.592	1.268	2.107	1.638	1.732	1.248	1.676	1.179
** Subtotal **	15.997	12.738	17.142	13.326	16.783	12.097	16.794	11.014
* SIC/DESCRIPTION 3								
27-PRINTING	0.559	0.445	0.791	0.615	0.699	0.504	0.741	0.521
38-INSTRUMENTS	0.449	0.357	0.524	0.408	0.621	0.448	0.673	0.474
23-APPAREL	0.398	0.317	0.509	0.396	0.473	0.341	0.488	0.343
25-FURNITURE	0.389	0.310	0.471	0.366	0.396	0.285	0.395	0.278
39-MISCELLANEOUS	0.754	0.600	0.464	0.360	0.357	0.257	0.379	0.266
31-LEATHER	0.279	0.222	0.258	0.201	0.155	0.112	0.160	0.112
21-TOBACCO	0.160	0.128	0.144	0.112	0.163	0.117	0.185	0.130
** Subtotal **	2.991	2.381	3.165	2.460	2.867	2.066	3.023	2.127
** Total **	99.999	99.999	99.999	99.999	99.999	99.999	99.999	99.999

SOURCE: See Appendix Table 1.

APPENDIX TABLE 3. US. Manufacturing sector. Steel, chemicals, and petroleum refining, aggregate energy input.

Year	Total Purchased Energy for Heat and Power	Energy Use as Raw Materials for Production of: Iron and Steel[a)]	Chemicals[b)]	Petroleum Refinery	Total	Total Aggregate Energy Input (as delivered)
		Trillion BTU				
1958	8248					
1962	9810					
1967	11810	1005	1032	982	3019	14829
1971	13140	1303	1405	1055	3763	16903
1974	13394	1366	1685	1291	4342	17736
1975	12047	1071	1483	1436	3990	15977
1976	12776	1050	1704	1556	4310	17086
1977	12928	744	1930	1663	4337	17265
1978	12931	652	2115	1807	4574	17505
1979	12869	785	2551	1649	4985	17854
1980	11873	932	2457	1615	5004	16877
1981	11563	838	2261	1519	4618	16181

a)Excludes waste fuels.
b)Includes electricity purchases of government operated plants.

SOURCE: 1982 Census of Manufactures. MC 82-S-4; part 1.

APPENDIX TABLE 4. US. Industry sector. The growth of production and energy input (primary energy).

	DOE Energy Consumption by the Industrial Sector (including electrical system energy losses)		FRB Industrial Production Index	Energy Input per Industrial Output (E/I = 100)
Year	Quad-Btu	1970=100	Index Numbers, 1970 = 100	
1951	17.41	60.04	45.16	132.95
1952	16.99	58.59	46.93	124.84
1953	17.86	61.59	50.89	121.03
1954	16.77	57.83	48.16	120.08
1955	18.99	65.48	54.30	120.60
1956	19.70	67.93	56.75	119.70
1957	19.46	67.10	57.44	116.83
1958	18.32	63.17	53.75	117.53
1959	19.74	68.07	60.16	113.14
1960	20.34	70.14	61.39	114.25
1961	20.44	70.48	61.94	113.80
1962	21.23	73.21	66.98	109.29
1963	22.17	76.45	70.94	107.76
1964	23.50	81.03	75.85	106.83
1965	24.47	84.38	83.36	101.23
1966	25.78	88.90	90.72	97.99
1967	26.00	89.66	92.77	96.64
1968	27.20	93.79	98.64	95.09
1969	28.40	97.93	103.14	94.95
1970	29.00	100.00	100.00	100.00
1971	28.96	99.86	101.77	98.12
1972	30.24	104.28	111.05	93.90
1973	31.54	108.76	120.46	90.28
1974	30.70	105.86	120.05	88.18
1975	28.41	97.97	109.28	89.65
1976	30.24	104.28	121.15	86.07
1977	31.09	107.21	128.24	83.60
1978	31.41	108.31	135.61	79.87
1979	32.62	112.48	141.47	79.51
1980	30.61	105.55	136.43	77.37
1981	29.25	100.86	140.11	71.99
1982	26.14	90.14	128.65	70.07
1983	25.91	89.35	136.97	65.23
1984	27.86	96.10	151.60	63.39

APPENDIX TABLE 5. US. Manufacturing sector. The growth of energy input per manufacturing output.

	Manufacturing Output		Energy Input		Energy Input per Manufacturing Output	
Year	FRB Production Index a)	Sales Values at 1972* Prices b)	Purchased Energy for Heat and Power, Final[c)]	Aggregate Primary Energy Equivalents[d)]	Purchased Energy for Heat and Power, Final	Aggregate Primary Energy Equivalents
	Index Numbers, 1971 = 100					
1967	92.4	94.5	90.8	87.1	98.2	92.2
1971	100.0	100.0	100.0	100.0	100.0	100.0
1974	119.5	115.7	104.1	108.5	87.1	93.8
1975	107.4	105.8	92.9	107.7	86.4	101.8
1976	120.3	115.7	98.2	98.5	81.8	85.1
1977	127.8	125.2	99.1	105.2	77.5	84.0
1978	135.6	131.5	99.2	108.5	73.1	82.5
1979	141.9	134.2	98.9	110.5	69.7	82.3
1980	135.6	128.3	91.8	105.7	67.7	82.4
1981	138.9	130.2[E]	88.9	101.7	62.8	78.1
1982	127.1	117.4[E]				
1983	136.8	125.9[E]				
1984	152.4					

*Real gross output.

a) FRB index from the Economic Report of the President, February 1985.

b) The index implicit in the sales values at 1972 prices is the same as that implicit in the *Manufacturing Real Output* in the DOE energy conservation indicators, 1983 Annual Report (DOE/EIA-0441(83), p. 103.

c) 1982 Census of Manufacturers, Fuels and Electric Energy Consumed MC 82-S-4 and earlier issues and 1980 Annual Survey of Manufacturers, Fuels and Electric Energy Consumed M 80(AS)-4.1 and earlier issues.

d) Purchased energy for heat and power plus estimated feedstocks for chemicals, petroleum refining, iron, and steel; converted to primary energy equivalents.

E Estimated.

APPENDIX TABLE 6. US. Industry sector. Comparison of indicators for production and energy input (index numbers, 1970 = 100).

	PRODUCTION			ENERGY INPUT		
		DOE Study				
Year	FRB Production Index	Energy Weighted Index of Industrial Output (relative to 1981)	Industrial Real Output	DOE End-Use Energy Consumption by Industrial Sector	DOE Energy Conservation Indicators Energy Consumption "Total"	DOE Energy Conservation Indicators Energy Consumption End-Use
1958	53.7			64.9		
1959	60.1			68.1		
1960	61.3	68.3	72.1	70.1	70.3	72.7
1961	61.9	68.8	72.8	70.5	70.6	72.9
1962	66.9	73.0	77.2	73.2	73.4	75.6
1963	70.9	79.4	81.3	76.4	76.6	79.6
1964	75.8	83.0	85.4	81.0	81.1	83.5
1965	83.3	88.5	90.8	84.3	84.5	86.6
1966	90.7	93.7	95.6	88.9	89.0	90.8
1967	92.7	93.3	96.9	89.6	89.8	91.1
1968	99.0	98.2	101.9	93.8	94.0	94.9
1969	103.1	102.8	104.3	97.9	98.1	98.5
1970	100.0	100.0	100.0	100.0	100.0	100.0
1971	101.7	100.7	102.5	99.8	99.8	99.2
1972	111.0	109.2	110.8	104.3	104.2	102.9
1973	120.4	116.9	117.4	108.7	110.0	108.3
1974	120.0	118.1	113.8	105.9	107.1	104.4
1975	109.2	103.8	104.2	97.9	99.1	95.1
1976	121.1	114.3	113.7	104.3	105.5	100.4
1977	128.2	121.5	121.3	107.2	108.5	102.8
1978	135.6	126.0	127.0	108.3	109.7	103.1
1979	141.4	128.3	128.9	112.5	113.9	107.3
1980	136.4	119.6	123.6	105.5	106.9	99.8
1981	140.1	120.5	125.3	101.7	102.1	94.3
1982	128.6	105.0	115.6	90.1	91.2	83.7
1983	136.9	105.0	118.9	89.3	90.9	82.2
1984	151.5			96.0		

SOURCES: FRB production index and DOE end-use energy consumption by the industry sector, see Appendix Table 1. DOE energy conservation indicators, "total" and end-use, see 1983 Annual Report DOE/EIA-0441(83), p.103.

APPENDIX TABLE 7. US. DOE/DRI industrial energy consumption per industrial output.

Year	Total Energy Consumption per Industrial Real Output	End-Use Energy Consumption per Industrial Real Output	Total Energy Consumption per Energy Weighted Production
	Index Numbers, 1970 = 100		
1960	97.4	100.6	102.9
1961	97.1	100.2	102.5
1962	95.0	97.8	100.6
1963	94.2	97.0	98.8
1964	95.0	97.7	97.9
1965	93.0	95.3	95.5
1966	93.0	94.9	94.9
1967	92.7	93.9	96.3
1968	92.2	93.0	95.7
1969	93.9	94.2	95.4
1970	100.0	100.0	100.0
1971	97.3	96.6	99.1
1972	94.0	92.7	95.5
1973	93.6	92.2	94.0
1974	94.0	91.6	90.6
1975	95.7	91.2	95.5
1976	92.8	88.3	92.3
1977	89.3	84.7	89.3
1978	86.3	81.1	87.0
1979	88.2	83.2	88.7
1980	86.5	80.7	89.4
1981	81.5	75.2	84.7
1982	78.8	72.3	86.9
1983	76.3	69.0	86.6

SOURCE: DOE/IEA Energy Conservation Indicators 1983 Annual Report, published October 1984, DOE/EIA-441(83), Table 32, p. 104.
NOTE: Base year of the index converted from 1973 to 1970 = 100.

APPENDIX TABLE 8. FRG. Manufacturing sector. The growth of energy input per manufacturing output since 1950.

YEAR	Manfacturing Output (Net Production Index)	Final Energy Input by Manufacturing	Energy Input per Manufacturing Output (P/M*100)
	Index Numbers, 1970=100		
1950	21.9	40.5	185.2
1951	26.3	47.2	179.2
1952	28.3	51.3	181.1
1953	30.5	50.2	164.4
1954	34.9	54.3	155.8
1955	40.8	61.3	150.3
1956	44.1	65.0	147.4
1957	46.1	65.3	141.7
1958	47.5	63.7	134.1
1959	51.5	65.5	127.2
1960	58.6	73.5	125.5
1961	62.3	74.3	119.3
1962	64.8	75.2	116.1
1963	66.9	76.7	114.6
1964	73.1	82.4	112.8
1965	77.4	84.6	109.3
1966	78.2	82.1	105.0
1967	76.1	81.9	107.6
1968	83.3	88.8	106.5
1969	94.2	95.5	101.4
1970	100.0	100.0	100.0
1971	101.6	97.5	95.9
1972	105.3	98.8	93.8
1973	112.6	104.4	92.7
1974	110.3	105.2	95.4
1975	102.7	92.7	90.2
1976	112.1	98.0	67.5
1977	115.3	97.4	64.4
1978	117.1	97.9	83.7
1979	123.0	102.3	63.2
1980	123.6	97.7	79.0
1981		92.1	
1982		84.0	
1983		84.1	

SOURCE: C. Doblin, Patterns of Industrial Change in the Federal Republic of Germany. WP-84-73. International Institute for Applied Systems Analysis, Laxenburg, Austria.

APPENDIX TABLE 9. France. Industry sector. The growth of energy input per industry output.

Year	Industrial Production Index	Final Energy Consumption by Industry	Energy Input per Industry Output E/I*100
	Index Numbers, 1970 = 100		
1962	62.06	72.41	116.68
1963	70.38	73.86	104.95
1964	75.07	79.76	106.25
1965	79.36	81.42	102.61
1966	81.64	83.09	101.79
1967	81.50	84.87	104.14
1968	87.27	88.10	100.95
1969	94.24	95.22	101.04
1970	100.00	100.00	100.00
1971	106.03	101.89	96.09
1972	110.99	106.23	95.71
1973	120.11	112.90	94.00
1974	123.06	119.35	96.99
1975	115.01	104.23	90.62
1976	123.99	109.90	88.63
1977	126.01	111.79	88.72
1978	129.09	113.01	87.55
1979	134.99	117.13	86.77
1980	134.05	111.23	82.98
1981	133.11	103.11	77.47
1982	0.00	0.00	0.00
1983	128.02	0.00	0.00
1984			

SOURCE: Industrial production index, excluding construction. See Annuaire Statistique de la France 1983 and earlier, updated with Bulletin Mensuel de la Statistique. Energy input, Comite National Francais de la Conference Mondiale de l'Energie. Syntinse des Bilans Energetique Francais 1962-1981.

APPENDIX TABLE 10. US. The growth of organic and inorganic chemicals (in lbs), included in the list of 50 top chemicals, 1970-1984.

ORGANIC CHEMICALS	1984	1983	1982	1981	1980	1979	1978	1977	1976	1975	1974	1973	1972	1971	1970
2869 ETHYLENE	172	158	135	162	158	165	143	139	124	113	132	123	115	101	100
2869 PROPYLENE	236	213	191	206	209	217	198	203	153	133	160	151	129	105	100
2869 ETHYLENE DICHLORIDE	184	154	102	133	148	158	147	147	107	106	122	124	104	101	100
2865 BENZENE	118	108	92	115	135	142	126	120	120	84	123	128	110	94	100
2869 ETHYLBENZENE	178	163	137	161	158	175	173	172	119	99	125	117	117	103	100
2861 METHANOL synthetic	167	161	153	173	145	149	130	130	126	104	139	143	131	93	100
2865 STYRENE MONOMER	177	156	137	154	158	172	165	158	145	107	137	137	137	108	100
2865 VINIL CHLORIDE	185	170	121	170	160	158	171	148	140	103	139	132	125	107	100
2865 o-XYLENE	87	97	100	114	124	135	126	123	106	87	132	133	104	98	100
2869 TEREPHTHALIC ACID	141	132	113	146	142	144	139	126	118	108	100	100	100	100	100
2869 ETHYLENE OXIDE	154	143	129	127	135	146	129	112	108	115	108	107	102	93	100
2869 FORMALDEHYDE	129	123	108	129	125	134	144	136	123	125	130	145	127	102	100
2865 TOLUENE	87	93	86	102	121	120	126	121	119	83	109	115	110	105	100
2869 ETHYLENE GLYCOL	159	145	141	136	144	155	128	120	109	125	109	107	123	101	100
2865 p-XYLENE	268	258	213	285	266	292	221	199	183	156	170	146	138	104	100
2865 CUMENE	169	168	138	166	174	197	170	133	136	101	146	134	115	108	100
2865 PHENOL	387	359	275	351	349	406	365	318	288	237	313	139	127	108	100
2869 ACETIC ACID	136	145	142	140	154	168	143	133	127	113	133	125	115	101	100
2869 BUTADIENE	81	75	61	96	90	115	113	105	113	83	118	117	113	107	100
2865 CYCLOHEXANE	115	89	69	98	106	131	126	123	118	94	127	115	124	94	100
2869 VINYL ACETATE	251	244	233	241	239	246	210	197	184	160	174	187	150	115	100
2861 ACETONE	116	115	104	132	128	164	155	137	115	101	122	123	112	95	100

INORGANIC CHEMICALS	1984	1983	1982	1981	1980	1979	1978	1977	1976	1975	1974	1973	1972	1971	1970
2819 SULFURIC ACID	134	123	112	137	149	140	139	129	116	109	114	108	105	98	100
2813 NITROGEN	398	370	319	324	317	282	250	217	191	166	160	150	128	111	100
2813 OXYGEN	96	87	89	110	116	110	100	99	90	100	100	100	100	100	100
2812 SODIUM HYDROXIDE	110	100	92	104	114	125	111	108	103	95	110	105	100	95	100
2812 CHLORINE GAS	109	102	93	110	116	125	113	108	106	93	110	106	100	95	100
2819 HYDROCHLORIC ACID	142	129	121	127	143	153	138	132	126	99	122	125	117	104	100
2819 AMMONIUM SULFATE	108	103	93	115	112	124	129	119	106	111	111	104	98	96	100
2819 SODIUM SULFATE	63	66	62	80	83	81	85	87	89	89	98	104	96	98	100
2816 SODIUM SILICATE	119	115	105	122	128	129	132	121	118	115	122	115	105	101	100
2816 TITANIUM DIOXIDE	121	115	100	116	110	113	107	104	108	92	120	119	105	103	100
281 NITROGEN GAS	398	370	319	324	317	282	250	217	191	166	160	150	128	111	100

SOURCE: Compiled from Chemical and Engineering News, List of 50 Top Chemicals.

APPENDIX TABLE 11. US. Electricity sales to manufacturing industries.

SIC	Purchasing industry	Million kWh									
		1967	1971	1974	1975	1976	1977	1978	1979	1980	1981
Total manufacturing		427465	517780	616665	596798	639935	663351	675721	682384	658104	665784
20	Food and kindred products	24401	35450	36874	38299	39062	40046	40522	39535	41118	41428
21	Tobacco manufactures	737	909	1028	1071	1124	1250	1266	1321	1393	1422
22	Textile mill products	20264	24952	26908	26555	28026	27609	26903	26521	25731	25580
23	Apparel	3595	5512	6357	6845	6756	6620	6744	5941	6050	6057
24	Lumber, wood products	7297	9314	14791	14385	15547	16125	16668	16066	14667	14528
25	Furniture	2474	3940	4064	3885	3969	4190	4255	4033	3952	4143
26	Paper and allied	25858	34999	40870	39120	43459	44560	45611	46161	49684	52199
261–263	Primary paper	NA	26000	34260	29737	33939	35113	35708	36332	39795	42208
27	Printing, publishing	5817	9596	8993	9934	10123	10554	10346	9488	9655	10302
28	Chemicals and allied	95414	99632	124168	127693	145423	149141	145548	145177	133195	132340
281	Industrial inorganic[a]	NA	NA	38700	34600	37800	38300	41200	38000	36900	36900
286	Industrial organic	NA	NA	22800	23300	27400	29600	31000	31600	31200	30100
282	Plastics, synthetics	9003	13700	17300	15200	16781	18583	19390	22054	20937	21287
2821	Plastics materials, resins	4368	NA	8132	7292	8207	9197	9998	12169	11865	12255
2822	Synthetic rubber	1570	NA	1690	1215	1307	1330	1377	1581	1417	1440
287	Agricultural chemicals	2294	3000	7900	8500	9454	9818	9745	9471	9665	9920
283	Drugs, pharmaceuticals	1886	2800	3305	3223	3500	3899	4065	4141	4492	4673
29	Petroleum, coal products	18186	23690	27240	26398	27713	30153	30262	31570	32212	32546
2911	Petroleum refining	17474	22600	25800	24900	26300	28500	28528	29886	30500	31000
30	Rubber, plastics products	10184	16397	19039	18793	19750	22556	22970	22838	21661	22913
3011	Tires and inner tubes	2675	NA	4637	4532	4437	5288	4916	4856	4057	4070
3079	Plastics products, misc.	7418	NA	11241	11382	12398	14043	14804	14681	14494	15554
31	Leather, leather products	1288	1708	1509	1527	1510	1416	1392	1271	1361	1321
314	Footwear, ex. rubber	NA	800	751	727	684	657	605	587	611	591

APPENDIX TABLE 11 (continued)

SIC	Purchasing industry	Million kWh									
		1967	1971	1974	1975	1976	1977	1978	1979	1980	1981
32	Stone, clay, glass products	19570	24851	28858	27799	29236	30925	32754	32986	30505	30064
3241	Cement, hydraulic	7495	8500	9905	8794	9140	9823	10413	10328	9283	8923
33	Primary metals	109469	122406	163319	137698	147642	157737	166515	173977	164248	165959
331	Iron and steel mills	44599	50000	61532	51191	54644	58613	61932	64255	56633	59520
3312	Blast furnace	34795	NA	49598	41203	44264	46952	50509	52633	47148	49378
3334	Aluminum, primary	41957	NA	68699	55633	58777	64761	68107	71579	72279	70889
3331	Copper, primary	860	NA	1538	1713	1728	1926	1935	2040	1428	1597
34	Fabricated metal products	14694	20303	25199	24261	24605	26387	26369	26296	25320	25539
35	Machinery, ex. electrical	16659	22323	26061	27338	27964	28441	30096	30373	30578	31569
3573	Electronic computing equipment	NA	NA	2097	2308	2283	2127	2577	2931	3389	4554
36	Electric & electronic equipment	19013	23569	24658	23607	23600	24997	26053	27320	27183	28027
3674	Semi-conductors	NA	NA	2140	2191	2296	2465	2628	3141	3508	4070
3679	Electronic components, n.e.c.	NA	NA	1366	1391	1448	1541	1662	1882	1990	2174
37	Transportation equipment	23468	27475	28375	27544	29536	30985	31771	31972	29968	30090
371	Motor vehicles and parts	12448	15800	15996	15705	17745	19282	19953	18930	16279	16983
372	Aircraft and parts	8402	8500	6746	6350	6191	6548	6944	7545	8311	7690
38	Instruments	2493	3627	4569	5083	5167	5533	5668	5841	5987	6128
39	Miscellaneous	6583[b]	7127[b]	3921	3818	3722	4123	3989	3694	3621	3631

[a]Excludes government operated plants.
[b]Includes ordnance.
Source: US Census of Manufactures.

APPENDIX TABLE 12. US. Energy savings through imports of selected energy intensive industries (annual data).

YEARS	STEEL MILL PRODUCTS			PRIM. ALUMINUM		BASIC COPPER	
	AGGR ENERGY INPUT a)	FUELS & ELECTR. b)	PURCH. ELECTR.	FUELS & ELECTR. b)	PURCH. ELECTR.	FUELS & ELECTR. b)	PURCH. ELECTR.
1960	85.0						
1961							
1965	209.0						
1970	290.8						
1971							
1972							
1973							
1974				42.89	7775	18.735	369
1975	255.6	145.8	5255	39.12	7452	11.275	253
1976				38.76	9092	23.341	580
1977	250.9	364.8	9027	54.13	10687	23.239	675
1978	375.6	274.5	9533	66.66	13800	26.048	768
1979	320.3	220.0	8250	56.37	10993	16.201	474
1980	320.9	191.4	7840	45.79	9194	24.094	649
1981	368.2	229.8	9801	53.96	12220	21.190	542
1982	309.0	192.9	8225	58.62	12803	15.522	397
1983							
1984							

YEARS	BASIC CHEMICALS: INORGANIC			ORGANIC		NITROGEN FERTILIZERS		
	FUELS & ELECTR. a)	PURCH. ELECTR. b)	AGGREG. ENERGY a)	FUELS & ELECTR. b)	PURCH. ELECTR.	AGGREG. ENERGY a)	FUELS & ELECTR. b)	PURCH. ELECTR.
1960								
1961								
1965								
1970								
1971								
1972			58.1	21.0		29.5	13.2	172
1973	23.3	1079	77.4	28.0	713	36.4	16.4	213
1974	25.2	1166	114.2	41.3	1051	45.8	20.6	268
1975	25.9	1201	86.9	31.4	800	44.3	19.9	259
1976	36.2	1676	91.8	33.2	845	42.6	19.1	249
1977	37.1	1720	101.2	36.6	932	65.1	29.3	381
1978	44.7	2069	131.6	47.6	1211	75.7	34.0	442
1979	41.9	1942	127.3	46.1	1172	71.0	31.9	415
1980	44.6	2067	123.5	44.7	1137	77.3	34.8	452
1981	39.0	1777	130.4	47.2	1201	69.5	31.2	406
1982								
1983								

YEAR	PETROLEUM REFINING			CEMENT		PRIM. PAPER		
	AGGREG. ENERGY INPUT a)	FUELS & ELECTR. b)	PURCH. ELECTR.	FUELS & ELECTR. b)	PURCH. ELECTR	TOTAL ENERGY	FUELS & ELECTR. b)	PURCH. ELECTR.
1960								
1961	210							
1965	284					337		8900
1970				14.9	276	371		9800
1971	476	287	4105	17.7	329			
1972				28.0	544			
1973				38.3	744			
1974	559	307	5051	34.0	684	412	210	12700
1975	399	192	3596	22.6	466	306	162	8800
1976	396	181	3638	18.0	381	357	182	10200
1977	393	178	3931	22.6	492	373	181	11000
1978	369	142	3817	36.2	812	435	214	12600
1979	356	153	3682	49.3	1128	405	197	11900
1980	336	133	3443	27.0	652	358	173	11000
1981	304	130	3545	21.1	480	341	165	11200
1982								
1983								

NOTE: All savings are in terms of final, delivered energy.

[a] Purchased energy for heat and power plus feedstocks.

[b] Purchased energy for heat and power.