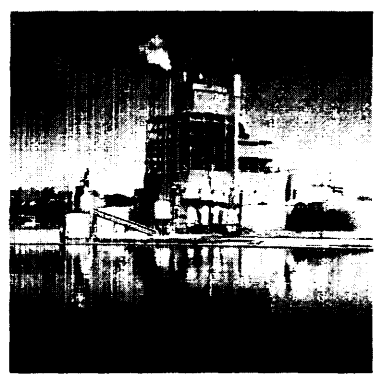
Industrial Energy Consumption 2

Industry is a diverse sector encompassing about half a million manufacturing, mining, agriculture, fishing, and forestry establishments and a like number of construction sites.[1] These many facilities, ranging from small diecasting shops, to family farms, to steel mills, to appliance manufacturers, and to semiconductor producers, vary greatly in their activities, size, and technological sophistication.

Energy use in industry is likewise heterogeneous. Each facility uses a different mix of fuels for a variety of purposes in converting raw materials into salable products. Industries vary greatly in their overall level of energy use, because of differences in their output and energy intensity (energy use per unit of output).

This chapter illustrates some of the broader trends and patterns in industrial energy use, while seeking to retain a flavor of the underlying complexity. Industry past and present energy situations are reviewed and estimates of the near-term future are presented. Except where noted, all energy consumption statistics are given in end-use terms (box 2-A).



OVERALL ENERGY CONSUMPTION

In 1990, U.S. industry consumed 25.0 quadrillion Btu (quads) of fuel and electricity.[2] This accounted for 27 percent of the Nation's total use of fossil fuels, 32 percent of its renewable energy use, and 35 percent of its electricity use (figure 1-2). An additional 7.2 quads were consumed in generating and delivering the electricity that industry used. Industry's overall share of total U.S. energy consumption depends how electricity generation, transmission, and distribution losses are handled. Industry accounts for 30 percent of U.S. energy use—if the losses are

[1] In the United States, oil and gas processing facilities are generally classified as part of the industrial sector, but utility-run electricity generation, transmission, and distribution facilities are part of the utility sector.

[2] Quad stands for 1 quadrillion (10^{15}) British thermal units (Btu). 1 quad= 1.05 exajoules (EJ).

Box 2-A—Energy Consumption Categories

Industrial energy use is measured in many ways. The following categories are the most important.

- End-use energy or direct energy—A measurement basis in which the energy content of fuels and electricity is calculated at their point of use. The end-use energy content of 1 kWh of electricity is 3,412 Btu.
- Primary energy-A measurement basis in which the energy content of fuels and electricity is calculated at the place of generation. The primary energy content of 1 kWh of electricity is about 10,500 Btu.
- Energy for heat, power, and electricity generation-Energy consumed in direct process uses (e.g., motor drive, process heating, cooling and refrigeration, and electrochemical processes), direct nonprocess uses (e.g., heating, ventilation, air conditioning, lighting, office equipment, on-site transportation, and conventional electricity generation), and indirect uses (e.g., boilers and cogenerators).
- Energy feedstocks-Energy products used as raw materials for nonenergy products (e.g., coke in steelmaking and petroleum in petrochemical, asphalt, wax, lubricant, and solvent production). W used either as a source of fiber in paper products or as the basis of furniture or lumber products meets the definition of an energy feedstock, but is not counted as such because data on its energy content are not available. In addition, petroleum that is refined into energy products (such as gasoline and other fuels) is a major energy input that does not qualify as feedstock. These wood and petroleum uses can be described as nonfeedstock energy material inputs.
- Energy byproducts-Byproducts of energy feedstocks and nonfeedstock energy material inputs that are used for heat, power, and electricity generation. These include: blast furnace gas and coke oven gas at steel mills; wood chips, wood waste, and pulping liquor at paper mills; and still gas and petroleum coke at petroleum refineries.
- Purchased energy-The portion of energy used for heat, power, and electricity generation and feedstocks that is produced off-site.
- Cogeneration-Cogeneration refers to the combined production of steam and electricity from the same fuel source. Typical fuels are natural gas, biomass, and various byproduct fuels, but coal and oil can be used as well. Care must be taken to avoid double counting the fuels consumed and the electricity generated.

The particular measure which is most important depends on the issues being examined. For example, carbon dioxide (CO_2) emissions are tied to the fuels, both purchased and byproduct, that are burned at the plant and the electric utility. Feedstocks and other energy material inputs have little affect on $C0_2$ emissions. Energy security is sensitive to imported energy, whether used for heat, power, and electricity generation or for feedstocks. Competitiveness is dependent on purchased energy and byproduct energy. In general, use of purchased energy hurts competitiveness and use of byproduct energy helps.

Unfortunately, data for the various measures are collected with varying frequency. Consistent data are therefore not always available for all periods. Except where noted, all energy consumption statistics in this study are given in end-use terms.

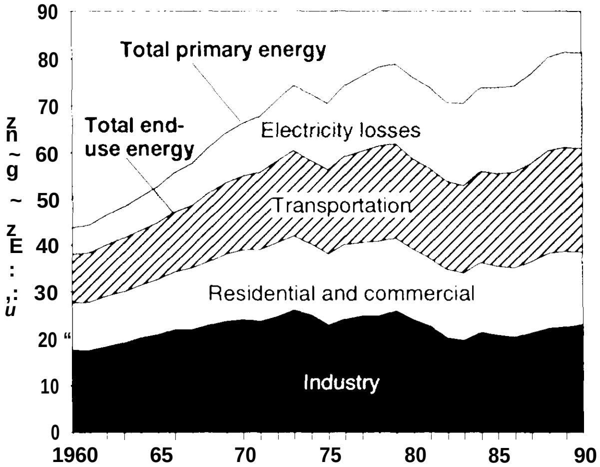
SOURCE: Office of Technology Assessment, 1993.

allocated to the electric utility sector, 38 percent—if the losses are allocated to the sectors using the electricity, and 39 percent-if the losses are disregarded altogether.

Industrial energy use has risen since 1983, but remains below its 1973 peak (figure 2-l). Consumption of traditional energy sources fluctuated from 26.1 quads in 1973 to about the same level in 1979, fell to 19.6 quads in 1983, and then rose to 23.0 in 1990.[3] Industry's relative share of U.S. energy use has generally declined in the last three decades. In 1960, the industrial sector accounted

[3] Traditional energy sources include coal, natural gas, petroleum and electricity used for heat power, electricity generatio~ and feedstock purposes; and excludes wood, waste, geothermal, wind, photovoltaic, and solar thermal energy. The 1990 figures in this paragraph differ slightly from those in the previous one, because renewable are included in the earlier figures and excluded in these.

Figure 2-1—U.S. Energy Consumption by Sector, 1960-90



SOURCE: U.S. Department of Energy, Energy Information Administration, State *Energy* Data *Report, Consumption Estimates 196(%1990,* Report No. DOE/EIA-0214(90), May 1992.

for 46 percent of all energy consumed in the United States for end-use purposes. By 1980, industry's share of energy use had fallen to 41 percent, and by 1990 it had slipped to 38 percent.[4]

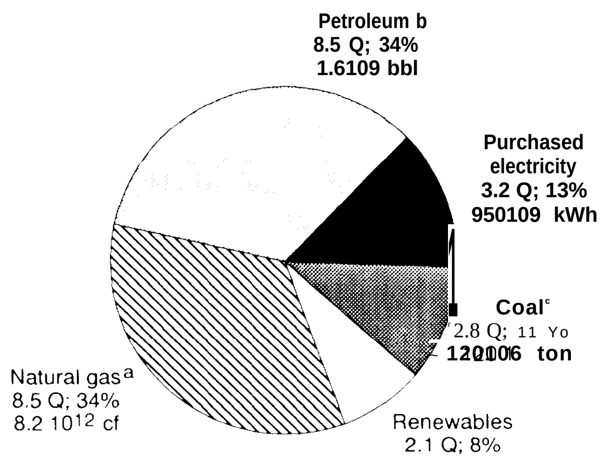
ENERGY SOURCES

Industry uses a wide array of energy sources, especially compared with the residential, commercial, transportation, and electric utility sectors. It consumes natural gas, petroleum, electricity, coal, and renewable, as well as many derivatives of these fuels. The petroleum products are particularly varied. They include distillate fuel oil, residual fuel oil, gasoline, liquefied petroleum gases (LPG), still gas, petroleum coke, asphalt, road oil, and lubricants.[5] Two major types of coal are used, steam and metallurgical. Steam coal is used in boilers, and metallurgical coal is used to make coke for iron production. Gases from blast furnaces, byproducts of the coke, are used for their heating value. Wood and byproducts of pulping, such as black liquor, are also used as energy sources.

The two largest sources of industrial energy are natural gas and petroleum products (figure 2-2). They account for nearly 70 percent of industrial energy use. Electricity is the third largest energy source in terms of end-use energy content, but is largest when generation, transmission, and distribution losses are included. Electricity also ac-

Figure 2-2—industrial Energy Consumption by **Fuel, 1990**

Total: 25.0 quads



a Natural gas includes lease and plant fuel, but excludes agricultural uses.

b petroleum: distillate fuel oil 1.2 Q; residual fuel oil 0.4 Q; gasoline 0.2 Q; LPG 1.6 Q; asphalt and road oil 1.2 Q; lubricants 0.4 Q; petrochemical feedstocks (including still gas and naptha) 1.1 Q;other (including petroleum coke) 2.5 Q.

[c] Coal: steam coal 1.7 Q, and metallurgical coal 1.0 Q.

NOTE: Industry's use of energy for feedstock and other nonfuel purposes accounts for about 48 percent of its petroleum use, 38 percent of its coal use, 8 percent of its natural gas use, and 23 percent of its total energy use.

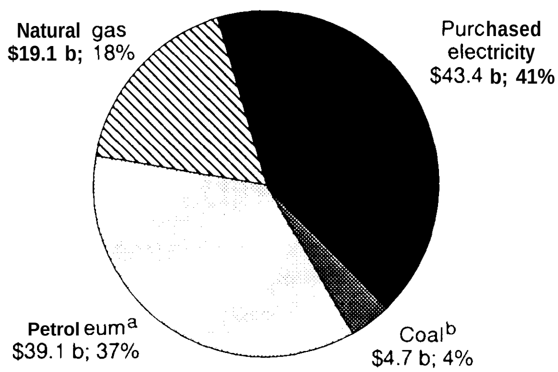
SOURCES: U.S. Department of Energy, Energy Information Administration, *State Energy Data Report, Consumption Estimates 1960-1990,* Report No. DOE/EIA-021 4(90), May 1992 and *Annual Energy Outlook 7993,* Report No. DOE/EIA-0383(93), January 1993,

[4] These percentages correspond to the case of disregarding electricity losses that was discussed the previous paragraph.

[5] LPGs are ethane, ethylene, propane, propylene, normal butane, butylene, and isobutane produced at petroleum refineries or natural gas processing plants. Still gas (also called refinery gas) is a byproduct gas produced during distillation, cracking, reforming, and other processes at petroleum refineries. Petroleum coke is a carbon residue produced during the cracking process at petroleum refineries. Catalyst petroleum coke, produced by burning off the carbon residue deposited on the catalyst, is used as a refinery fuel. Marketable petroleum coke, produced in delayed or fluid cokers, is a relatively pure form of carbon that can be sold as is or further purified by calcining.

Figure 2-3-industrial Energy Expenditures by Fuel, 1990

Total: $106 billion



a petroleum: distillate fuel oil $6.7 b; residual fuel oil $1.1 b; gasoline $1.7 b; LPG $8.5 b; asphalt and road oil $3.5 b; lubricants $8.0 b; other $9.6 b.
b Coal:steam coal $2.8 b, and metallurgical coal $1.9 b.

SOURCE: U.S. Department of Energy, Energy Information Administration, *State Energy Price and Expenditure Report 7990,* Report No. DOE/EIA-0376(90), September 1992.

counts for the largest share of industrial energy expenditures (figure 2-3).

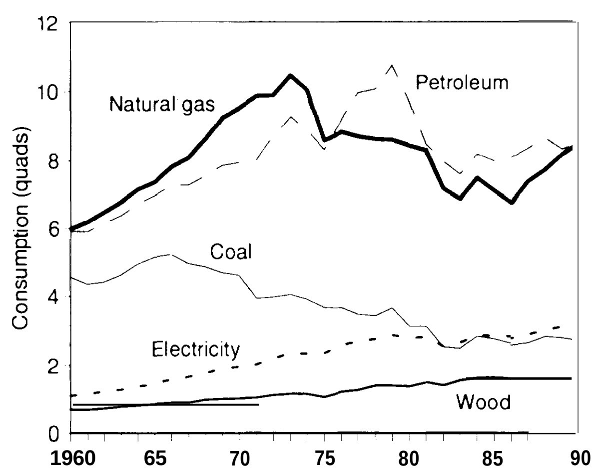
The mix of industrial energy sources has shifted during the last three decades (figure 2-4). Natural gas and petroleum have alternated as the most used industrial energy source. Natural gas was the largest energy source until the mid- 1970s. Use of natural gas began declining in 1974, because of supply curtailments and price rises. Several years later petroleum became the largest energy source. The decline in petroleum use from 1980 until 1983, and the faster growth in natural gas use in the late 1980s, led to natural gas and petroleum consumption being nearly equivalent in 1990. There were large shifts in the use of the various petroleum products during these 30 years. Consumption declined for residual fuel oil and gasoline, and increased for LPG, asphalt and road oil, distillate fuel oil, and other petroleum products.6 Coal was the third most used energy source until 1982 when it was overtaken by electricity. Electricity and wood consumption rose steadily during the three decades.

Prices

Energy prices are an important factor in the overall energy consumption of industry and in the mix of fuels it uses. High prices encourage energy conservation and also shifts to the use of relatively inexpensive fuels. Likewise, low energy prices discourage corporate attention to energy efficiency and conservation.

Energy prices vary across the sectors (table 2-l). Industry pays less for energy than the residential, commercial, and transportation sectors, but more than the electric utility sector. Industry and utilities pay lower prices because they can purchase bulk supplies. In 1990, industry paid 37 to 48 percent less for natural gas and 34 to 39 percent less for electricity than the residen-

Figure 2-4—industrial Energy Consumption by Fuel, 1960-90



SOURCES: U.S. Department of Energy, Energy Information Administration, State *Energy Data Report, Consumption Estimates 1960-1990,* Report No. DOE/EIA-0214(90), May 1992 and *Annual Energy Review* 1991, Report No. DOE/EIA-0384(91), June 1992. US. Department of Commerce, Office of Business Analysis, "National Energy Accounts database."

[6] From 1960 to 1990, consumption declined for residual fuel oil (74 percent) and gasoline (52 percent), and increased for LPG (229 percent), asphalt and road oil (59 percent), distillate fuel oil (16 percent), and other petroleum products (132 percent).

Table 2-1—Sectoral Energy Prices, 1990

	industry	Residential	Commercial	Transportation	Electric utilities	Measurement
Electricty	**$0.047**	**$0.078**	**$0.072**	**$0.081**	–	**$/kWh**
Natural gas.	**3.03**	**5.80**	**4.83**	—	**2.40**	**$/thousand cf**
Petroleum						
Distillate fuel oil	**0.79**	**1.11**	**0.85**	**1.17**	—	**$/lgallon**
Residual fuel oil	**0.46**	—	**0.51**	**0,45**	—	**$/gallon**
LPG	**0.46**	**0.94**	**0.74**	**0,73**	—	**$/gallon**
Coal						
Steam	**36.60**	**69.87**	**37.02**	—	**30.35**	**$/short ton**
Metallurgical,	**47.97**	—	—	—	—	**$/short ton**
Electricity	**13.92**	**22.96**	**21.20**	**23.64**	—	**$/million Btu**
Natural gas.	**2.94**	**5.63**	**4.69**	—	**2.32**	**$/million Btu**
Petroleum						
Distillate fuel oil	**5.68**	**8.01**	**6.10**	**8.46**	—	**$/million Btu**
Residual fuel oil	**3.10**	—	**3.43**	**2.98**	—	**$/million Btu**
LPG	**5.40**	**10.94**	**8.61**	**8.46**	—	**$/million Btu**
Coal						
Steam	**1.63**	**3.02**	**1,60**	—	**1.45**	**$/million Btu**
Metallurgical.	**1,79**	—	—	—	—	**$/million Btu**

NOTE: The weighted average industrial price for steam and metallurgical coal was $40.71 per short ton or $1.69 per million Btu.

SOURCE: U.S. Department of Energy, Energy Information Administration, State *Energy Price and Expenditure Report 7990,* Report No. DOE/EIA-0376(90), September 1992.

tial and commercial sectors. It paid about 27 percent more for natural gas and 12 percent more for coal than electric utilities.

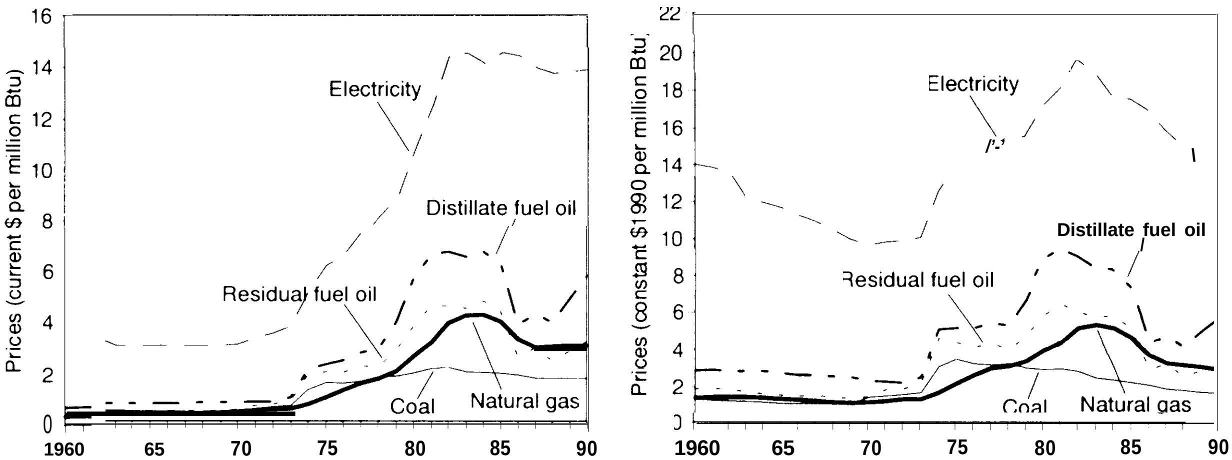
Industrial energy prices were stable until the 1974 oil shock and then rose until the early -1980s (figure 2-5). Since then fuel oil prices have fallen sharply, natural gas prices have declined moderately, and electricity and coal prices have remained stable. In real terms, prices after 1973 quadrupled for distillate fuel oil and natural gas, tripled for residual fuel oil, and doubled for electricity and coal. By the late 1980s, real prices had fallen from their peaks, but were still higher than their 1973 levels.

H Electrification

Use of electricity grew faster than other energy sources during 1960 to 1990. This occurred despite electricity being several times more expensive per Btu than other energy sources. The growth is the result of electricity's superior quality, flexibility, and environmental cleanliness at the point of use. Electricity is a higher quality source of energy than others, because a greater portion of its energy content can be converted into useful work during any given task. It is flexible in the sense that it can be used for heating, cooling, electrolytic, and motive purposes. Electricity performs tasks in industrial facilities in an environmentally clean manner. The environmental problems associated with electricity use occur at the generation and transmission stages, not at the end-use stage.

Electricity is used not as a simple substitute for other fuels, but to perform functions that require electricity or where the efficiency of electricity is higher than that of competing fuels. This illustrates that though different forms of energy can be discussed in terms of a common unit, such as Btus, their utility for specific uses varies.

Figure 2-5-industrial Energy Prices, 1960-90 (current $) and (constant $)



SOURCES: U.S. Department of Energy, Energy Information Administration, State *Energy Price and Expenditure Report 1990,* Report No. DOE/EIA-0376(90), September 1992 and Annual Energy Review 1991, Report No. DOE/EIA-0384(91), June 1992. U.S. Department of Commerce Office of Business Analysis, "National Energy Accounts database."

1 Fuel Switching Potential

Many industrial processes have the capability of using multiple energy sources. This provides flexibility to react to short-term price and availability conditions and also leverage to secure favorable fuel contracts with utilities.

The U.S. Department of Energy (DOE) surveys manufacturing establishments' short-term capability of switching energy sources.[7] The survey measures the potential for substituting one energy source for another within 30 days with no significant modifications to the fuel-consuming equipment and with production kept constant, The 1988 survey shows that manufacturers could have replaced about 42 percent of fuel oil and LPG use with nonpetroleum alternatives such as natural gas and coal (table 2-2). However, this substitution would have reduced manufacturers' total petroleum use by only about 5 percent. The overall substitution potential for petroleum is low, because most petroleum is used in feedstocks or in refinery operations, and only a relatively small amount is used as a fuel by choice. Backup fuels could have substituted for 39 percent of natural gas, 29 percent of coal and coke, and 2 percent of electricity. The greatest substitution potential occurs among the fossil fuels. Natural gas is the principle substitute for fuel oils and coal and coke. Fuel oils and LPG are the principal substitutes for natural gas.

The discretionary consumption range of an energy source gives an indication of its flexibility (figure 2-6).[8] Natural gas has the greatest flexibility in terms of Btu, and the fuel oils are the most flexible in percentage terms. In 1988, manufacturers were operating near the minimum consumption level for fuel oils and near the maximum level for natural gas.

I Cogeneration

Cogeneration is the combined production of heat (usually steam) and electricity from the same

[7] U.S. Department of Energy, Energy Information Administration, *Manufacturing Fuel-Switching Capability 1988,* Report No. DOE/EL4-0515(88), September 1991.

[8] Discretionary consumption is the sum of the potential increase and the potential decrease in the use of an energy source. Put another way, it is the difference between the potential maximum and minimum consumption of an energy source.

Table 2-2—Fuel Switching Potential, 1988 (trillion Btu)

	Petroleum.	Natural gas	Coal and coke	Electricity
Actual consumption	*888*	*5,306*	1,980	2,485
Switching away from fuel				
Potential decrease	374	2,072	568	38
Alternative fuels				
Natural gas	314	—	371	29
Purchased electricity	19	90	39	—
Coal and coke	24	111	—	4
Distillate fuel oil	—	916	172	11
Residual fuel oil		811	240	16
LPG	—	691	20	8
Other nonpetroleum fuels	21	61	35	2
Switching toward fuel				
Potential increase	NA	667	138	144

a Petroleum includes distillate fuel oil, residual fuel oil, and LpG.

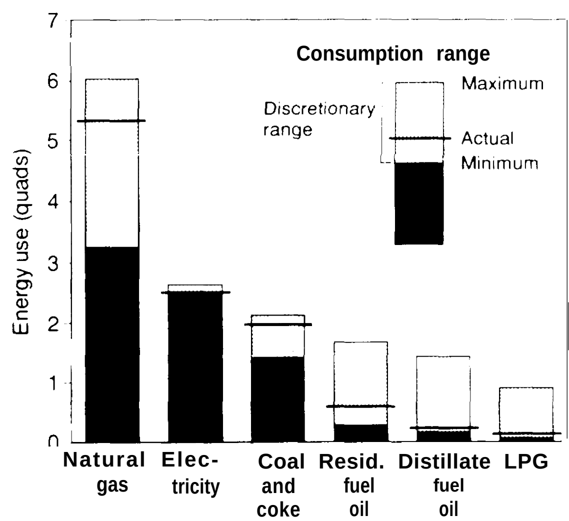
NOTE: Data are for the manufacturing sector only. Agriculture, forestry, fishing, mining, and construction are not included. Actual consumption is energy for heat, power, and electricity generation. Electricity consumption is off-site produced energy. Sum of alternative fuels does not equal potential decrease, because of redundancies.

SOURCE: U.S. Department of Energy, Energy Information Administration, Manufacturing *Fuel-Switching* Capability *7988,* Report No. DOE/EIA-0515(88), September 1991.

energy source, Conventionally, separate processes are used to produce steam and generate electricity. Both processes generate excess heat. Combining the two processes makes use of the excess heat and greatly increases overall fuel efficiency. Cogeneration is economic mostly in applications where heat of low-to-moderate temperature is needed on a regular basis, but is used in many high temperature applications as well. In 1988, about 12 percent of manufacturers' electricity demand was met through cogeneration. Paper, chemicals, petroleum, steel, and food companies are the principle cogenerators.

Cogeneration is a special kind of fuel switching. It gives manufacturers the ability to switch between electricity purchased from a utility and that produced on-site. This provides manufacturers with an additional method of responding to changing electricity and fossil fuel prices and availability. It can also increase companies' bargaining power with their utilities. The threat of

Figure 2-6--Manufacturers' Discretionary Energy Consumption Ranges Resulting From Fuel-Switching Capability, 1988



SOURCE: U.S. Department of Energy, Energy Information Administration, *Manufacturing Fuel-Switching Capability 7988,* Report No. DOHEIA-0515(88), September 1991.

Table 2-3—Energy Consumption by Functional Uses, Industry, and Energy Source, 1985 (trillion Btu)

	Steam	Direct process heat	Machine drive	Electrolytic	Space heat	Feedstocks	Miscellaneous	Cogeneratad electric	Total
Petroleum refining a.	1,100	1,300	200	—	<50	—	<50	<50	2,600
Chemicals	1,300	500	600	100	<50	1,300	<50	100	3,700
Pulp and paper	1,700	200	400		<50		<50	100	2,200
Food	400	400	200	—	<50	—	<50	<50	900
Primary metals	400	900	200	300	<50	1,000	100	<50	2,900
Ceramics and glass	<50	700	100	.	<50	—	<50	<50	900
Metals fabrication	200	400	400		100	.	100	<50	1,200
Nonmetals fabrication ., . .	300	200	200		<50		<50	<50	800
Miscellaneous	100	100	100	—	<50		<50	<50	300
Total	5,500	4,600	2,400	400	300	2,300	300	200	15,500
Electricity	—	—	1,700	400	100	—	300	200	2,200
Natural gas	1,600	2,800	300	<50	200	500	—	—	5,400
Fuel oil	900	200	100	<50	100	<50	—	—	1,300
Coal and coke	1,000	300	100	<50	<50	1,000		—	2,400
LPG	—	—	—	—		700	—	—	700
Other gas	700	1,200	200			—		—	2,100
Biomass	1,300	—	100	—	—	—	—	—	1,400
Total	5,500	4,600	2,400	400	300	2,300	300	200	15,500

a petroleum refining does not include feectstocks and raw materials inputs for the production of nonenergy products such as asphalt, waxes, lubricants, and solvents.

NOTE: Data are very rough estimates and cover the manufacturing sector only (agriculture, forestry, fishing, mining, and construction are not included). Figures may not add to totals because of rounding.

SOURCE: Office of Technology Assessment estimate, based on Industrial Sector Technology Use Model (ISTUM1).

installing cogeneration capacity can pressure utilities into giving more favorable terms in power contracts. In addition, cogeneration is a way of recouping the value from combustible byproducts of production processes, such as wood chips, black liquor, and blast furnace gas.

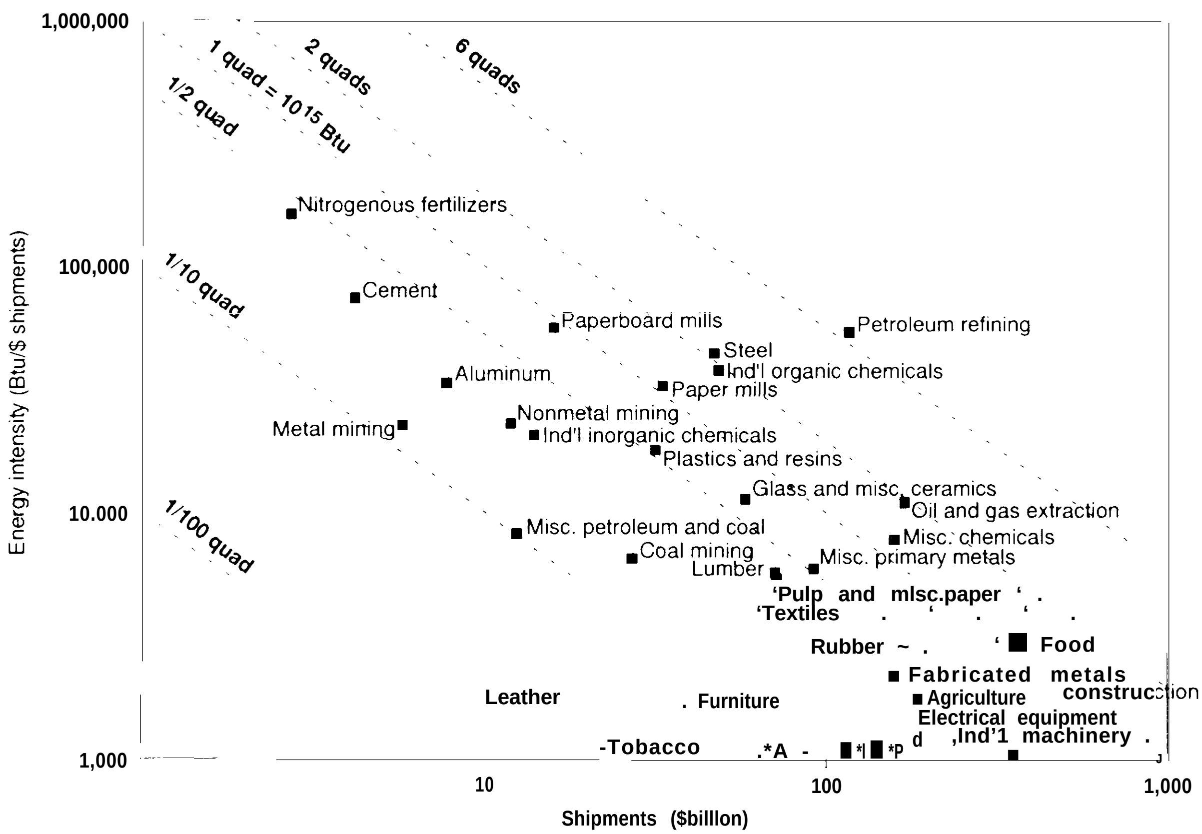
I Functional Use

Industry uses energy for a variety of purposes. Steam production via conventional boilers and cogenerators is the largest use (table 2-3). It is fueled in most industries by fossil fuels, primarily natural gas. The principal fuels for steam production in the pulp and paper industry are wood and black liquor; in the steel industry, blast furnace gas. Direct process heat is the second largest energy use. About two-thirds of process heat is fueled by natural gas. It is the most diverse of the functional use categories. It includes the heating of fluids and the heating, treating, melting, curing, forming, bonding, drying, calcining, firing, agglomeration, and smelting of various materials.[9] It is carried out in many different types of equipment including furnaces, ovens, driers, kilns, and process vessels.

Electric motor drive, which includes motors and the corresponding pumps, fans, compressors, and materials processing and handling is the next largest category. A small amount of shaft power, mostly in oil and gas drilling facilities and chemical plants, is provided by reciprocating engines or steam turbines fueled by natural gas and LPG. The next largest energy use is feedstocks, primarily natural gas in the chemicals

9 Process heating categories drawn from Gas Research Institute, *Industrial Natural Gus Markets: Facts, Fallacies* and *Forecasts*, GRI-88/0316 (Chicago, IL: Gas Research Institute, March 1989).

Figure 2-7—industrial Energy Intensity and Value of Shipments, 1988 and 1985



KEY: Several data points lie slightly below the 1,000 Btu/$ shipments energy intensity axis. ● A is Apparel at 830 Btu/$; ● 1 is Instruments at 990 Btul$; ● P is Printing at 810 Btu/$; *T is Transportation Equipment at 990 Btu/$.

NOTE: Diagonal lines represent levels of total energy use, rising from bottom to top and left to right. For any industry, the closest line shows the approximate amount of energy the industry consumed. For example, the petroleum refining industry consumed approximately 6 quads of energy. Industries that lie high and far to the right of the graph are larger overall energy consumers than those that lie close to origin.

Data for manufacturing industries are 1988 and for nonmanufacturing industries 1985. Intensities are based on energy consumption for heat, power, electricity generation, nonfuel uses, and oil and gas lease and plant fuel.

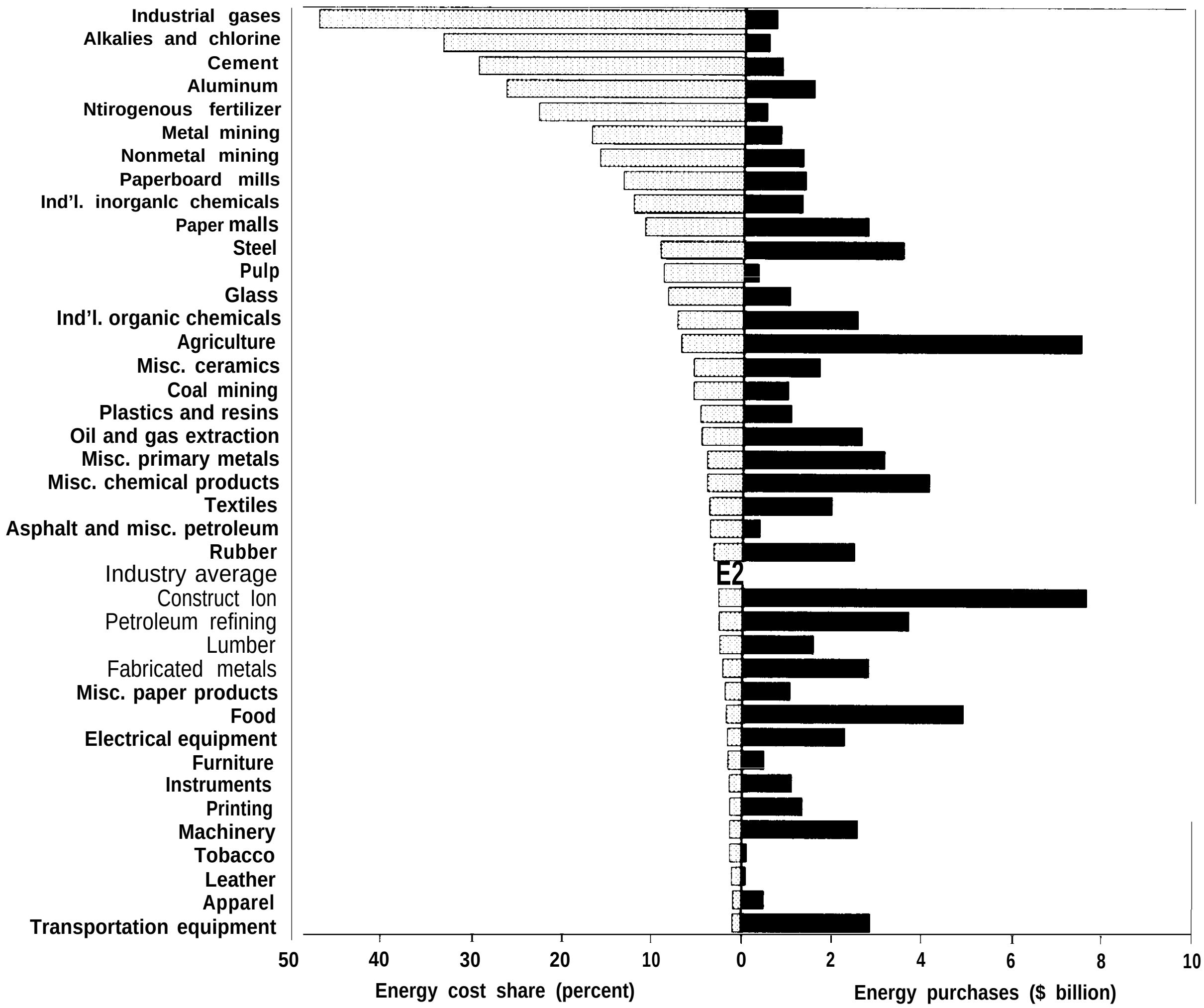
SOURCES: Manufacturlng: U.S. Department of Energy, Energy Information Administration, Manufacturing *Energy Consumption Survey (MECS), Consumption* of Energy 1988, Report No. DOE/EIA-0512(88), May 1991 and U.S. Department of Commerce, Bureau of the Census, 1988 *Annual Survey of Manufactures, Statistics for Industry Groups and Industries,* Report No. M88(AS)-1, October 1990. Nonmanufacturlng: U.S. Department of Commerce, Office of Business Analysis, "National Energy Accounts database." and Bureau of Labor Statistics, "Output and employment database. "

industry and coal in the steel industry. The remaining functional uses, electrolytic, space heat, and miscellaneous, are relatively small.

INDUSTRIES AND THEIR ENERGY USE

Energy consumption varies greatly among industries, because of differences in industry output and energy intensity (figure 2-7). Energy intensity differs among industries by a factor of 200. For example, nitrogen fertilizers require 160,000 Btu per dollar of product shipped and printing requires 810 Btu per dollar of product shipped. Industries such as petroleum refining, steel, organic chemicals, and paper use large quantities of energy because their energy intensity and their output are both high. Other less

Figure 2-8—Energy Purchases and Their Share of Production Costs, 1990 and 1987



NOTE: Data for manufacturing industries are 1990andfornonmanufacturing industries 1987. Costs of purchased energy include: electricity and fuels consumed for heat, power, and electricity generation. Production costs include: purchased energy; materials, goods, parts, containers, scrap, and supplies for production, repair, or maintenance; contract work (except in the construction industries); bought and resold products; and labor (including wages, nonwage benefits, and social security and other legally required payments).

SOURCES: U.S. Department of Commerce, Bureau of the Census, 1990 *Annual Survey of Manufactures:* Statistics *for Industry Groups and Industries,* Report No. M90(AS)-1, March 1992; 1987 Census *of Agriculture: United States Summary and State Data,* Report No. AC87-A-51, November 1989; 1987 *Census of* Mineral *Industries: General Summary,* Report No. MIC87-S-1, March 1991; 1987 *Census of Constriction Industries: United States Summary,* Report No. CC87-I-28, March 1990.

energy-intensive industries, such as oil and gas extraction, food, and construction consume large amounts of energy because of their large output.

Energy costs, in terms of overall expenditures and share of production costs, are also vastly different among industries (figure 2-8). For most industries, energy represents only a small portion of production costs. Energy accounts for 5 percent or less of production costs for 86 percent of industrial output. The industry average for energy as a share of production costs is 3.0 percent. Some industries have much higher energy costs though.

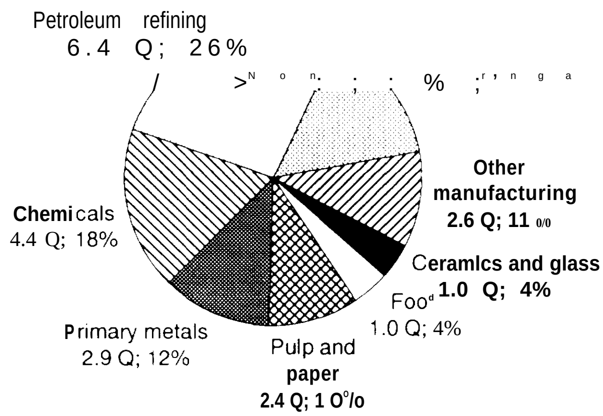
Producers of industrial gases, lime, alkalies and chlorine, cement, aluminum, and nitrogenous fertilizers have energy costs that exceed 20 percent of production costs.10

The largest energy users are industries, such as petroleum refining, chemicals, primary metals, pulp and paper, food, and ceramics and glass, that chemically or physically transform matter (figure 2-9 and table 2-4). These industries account for 74 percent of total industrial energy use. The fabricating and assembly industries (e.g., automotive manufacture, textiles, and metal fabricators) consume relatively little energy. However, they are comparatively large electricity users, because of the relative prominence of motor-driven devices, lighting, and ventilation. Nonmanufacturing establishments engaged in agriculture, fishing, forestry, mining, and construction account for the remaining 15 percent of industrial energy consumption.

The following discussion of energy consumption patterns is organized according to groups of industries that share similar energy use characteristics. The categories are: process industries, materials production, metals fabrication, nonmetals fabrication, and nonmanufacturing.11

Figure 2-9—industrial Energy Consumption by Industry Sector, 1988

Total: 24.2 quads



a Nonmanufacturing includes natural gas used as lease and plant fuel, but excludes agricultural uses of natural gas.
b Other manufacturing: metals fabrication 1.4 Q, nonmetals fabrication *0.9 Q*, and miscellaneous 0.3 Q.

SOURCES: U.S. Department of Energy, Energy Information Administration, *Manufacturing Energy Consumption Survey (MECS), Consumption of Energy 1988,* Report No. DOE/EIA-051 2(88), May 1991 and State *Energy Data Report, Consumption Estimates 1960-1990,* Report No. DOE/EIA-0214(90), May 1992.

I Process Industries

The process industries group encompasses: petroleum refining (SIC 29), chemicals (SIC 28), pulp and paper (SIC 26), food (SIC 20), textiles (SIC 22), and tobacco (SIC 21). It is the largest industrial energy consuming sector, using 14.4 quads in 1988. These industries convert raw materials into finished products primarily by chemical, rather than physical, means. Heat is an integral part of the processes. Steam provides much of this heat, and in addition, serves as a pressure agent. Steam production consumes about half of the energy used by these industries, varying from 77 percent in pulp and paper production to 35 percent in petroleum refining. Because of this heavy use of steam, cogeneration is particularly attractive in this sector, An additional 25 percent of the energy used in these industries is for direct process heating purposes such as fluid heating and materials drying. Motor drive and chemical feedstocks account for 15 and 13 percent of consumption, respectively .12

Natural gas is the largest source of energy to this sector, accounting for 26 percent of energy consumption. Noncommercial fuels, such as proc-

10 U.S. Department of Commerce, Bureau of the Census, *1990 Annual Survey of Manufactures: Statistics for Industry Groups and Industries,* Report No. M90(AS)-1, March 1992.

11 These categories are drawn from a taxonomy presented in Electric Power Research Institute, *Electrotechnology Reference Guide, Revision 2,* EPRI TR-101021 (Palo Alto, CA: Electric Power Research Institute, August 1992).

12 Figures for functional uses of energy are rough estimates made by the Office of Technology Assessment (OTA), based on data from the Industrial Sector Technology Use Model (ISTUM1).

Table 2-4—Energy Consumption by Industry and Energy Source, 1988 (trillion Btu)

	SIC[a]	Net electricity[b]	Natural gas	Fuel oil	Coal and coke	LPG	Other	All fuels
Process industries								
Petroleum refining	29	106	723	126	8	56	5,393[c]	6,412[d]
Chemicals	28	416	2,049	138	317	896	545[e]	4,360
Plastics and resins	2821	44	207	11	31	225	49	567
Nitrogenous fertilizers	2873	10	427	<.5	0	W[f]	W[f]	444
Miscellaneous industrial organic chemicals	2869	53	687	26	91	583	384	1,823
Miscellaneous industrial inorganic chemicals	2819	93	135	8	43	<.5	8	288
Other chemicals	—	216	593	110	152	<88	<104	1,238
Pulp and paper	26	189	431	190	315	5	1,236[g]	2,366
Paper mills	2621	98	179	103	191	2	507	1,081
Paperboard mills	2631	36	160	57	113	<.5	530	896
Other pulp and paper		55	92	30	11	3	199	389
Food	20	171	489	83	157	10	85	994
Textiles	22	101	93	26	39	3	12	275
Tobacco	21	3	2	1	17	<.5	1	25
Total process industries		987	3,787	564	852	969	7,272	4,432
Materials production								
Primary metals production	33	509	751	60	1,505	6	45	2,875
Steel	3312	138	444	47	1,418	1	18	2,067
Aluminum	3334	225	20	<.5	W[f]	<.5	9	258
Other primary metals		146	287	13	<87	5	18	550
Ceramics and glass	32	115	468	50	301	4	27	966
Cement (hydraulic)	3241	33	30	5	224	<.5	15	311
Other ceramics & glass		82	438	45	77	4	12	655
Total metal production	—	624	,219	109	1,806	10	72	3.841

Table 2-4—Energy Consumption by Industry and Energy Source, 1988 (trillion Btu)—Continued

	SIC[a]	Net electricity[b]	Natural gas	Fuel oil	Coal and coke	LPG	Other	All fuels
etals fabrication								
Transportation equipment	37	127	139	30	[illegible]	2	9	350
Fabricated metals	34	106	204	12	[illegible]	4	10	346
Machinery	35	114	129	12	[illegible]	3	3	280
Electronic equipment	36	109	85	10	[illegible]	3	6	224
Instruments	38	49	32	8	[illegible]	W[f]	2	113
Miscellaneous manufacturing	39	14	20	3	[illegible]	1	1	41
Total metals fabrication	—	519	609	75	[illegible]	13	31	1,354
Nonmetals fabrication								
Lumber and wood	24	56	35	26	2	3	285[h]	407
Rubber and plastics	30	07	111	19	9	3	4	253
Printing and publishing	27	58	49	3	0	2	4	116
Furniture	25	19	23	5	3	1	12	63
Apparel	[illegible]	23	22	4	3	1	1	54
Leather	[illegible]	5	5	4	1	<.5	<.5	16
Total nonmetals fabrication	—	268	244	61	18	10	306	909
Total manufacturing	—	2,398	5,859	809	2,782	[illegible]	7,681	20,536
Nonmanufacturing (1985 data)								
Agriculture, forestry, and fishing	1,2,7,8,9	112	54	55	[illegible]	[illegible]	0	295
Coal mining	12	56	1	91	[illegible]	[illegible]	0	156
Metal mining	10	55	17	19	[illegible]	[illegible]	0	122
Nonmetal minir	14	39	100	5	[illegible]	[illegible]	0	257
Oil and gas[i]	13	138	1,274	[illegible]	[illegible]	[illegible]	209	1,838
Construction	5,16,17	62	75	[illegible]	[illegible]	[illegible]	610[j]	792
Total nonmanufacturing		462	1,52[illegible]	447	109	103	9	3,460

[a] Standard Industrial Classification (SIC) codes.
[b] Net electricity refers to purchased electricity plus generation from noncombustible renewables minus electricity sales. It does not include electricity generated or cogenerated from combustible fuels accounted for elsewhere in the table.
[c] Includes: petroleum feedstocks and raw material inputs for the production of nonenergy products such as asphalt, waxes, lubricants, solvents, and feedstock consumption at adjoining petrochemical plants (3,290 trillion Btu); still gas (1,508); and petroleum coke (538).
[d] Excludes inputs and feedstocks that were converted to other energy products (e.g., crude oil converted to residual and distillate fuel oils).
[e] Includes: waste gas (263 trillion Btu); petrochemical feedstocks (199); and waste oils and tars (66).
[f] Withheld for data disclosure or data sampling reasons.
[g] Includes: pulping liquor (833 trillion Btu) and wood chips and bark (348).
[h] Includes: wood chips and bark (264 trillion Btu).
[i] Includes lease and plant fuel.
[j] Asphalt, road tar, and road oil used for nonenergy activities.

SOURCES: **Manufacturing data**: U.S. Department of Energy, Energy Information Administration, *Manufacturing Energy Consumption Survey (MECS), Consumption of Energy 1988*, Report No. DOE/EIA-0512(88), May 1991. **Nonmanufacturing data**: U.S. Department of Commerce, Office of Business Analysis, "National Energy Accounts Database."

ess **waste gas, petroleum coke, and waste oils and** tars in the petroleum and chemical industries, and pulping liquor and wood chips and bark in the pulp and paper industry are also large sources of energy. Combined, they account for 25 percent of the sector's energy consumption. Feedstocks for the production of asphalt, waxes, lubricants, solvents, and petrochemicals are the next largest with 24 percent of consumption. The remainder is accounted for by electricity (7 percent), LPG (7 percent), coal and coke (6 percent), fuel oil (4 percent), and miscellaneous energy (2 percent).

PETROLEUM REFINING

The petroleum refining industry is the largest energy consuming industry. Most of the heat and power needs are met with fuels, such as still gas, catalyst petroleum coke, fuel oil, and LPG, that are derived from the refining process itself. Consumption of on-site generated fuels, notably still gas and catalyst petroleum coke, has increased steadily during the last decade.[13] In 1988, these byproduct fuels met approximately two-thirds of heat and power requirements. Purchased energy made up the remaining one-third, and in 1990 accounted for about 2.6 percent of the industry's production costs.[14]

The industry's energy consumption and intensity declined quickly in the 1970s and more gradually in the 1980s (figure 2-10a). From 1974 to 1988, energy consumption fell by 30 percent and energy intensity fell by 45 percent.

CHEMICALS

The chemical industry, the second largest energy consuming industry, is a diverse set of establishments that produce organic and inorganic chemicals, plastics, synthetic rubber, soaps,, paints, industrial gases, fertilizers, pesticides, pharmaceuticals, and miscellaneous other products. Natural gas is the principal fuel in most chemical production processes, but electricity plays a large role in the production of nitrogenous fertilizers, chloralkalies, and industrial gases, which are produced electrolytically. Large quantities of natural gas, LPG, and still gas from petroleum refineries are used as feedstocks. Natural gas (methane) is used as a feedstock in the production of ammonia (a major component of fertilizers), hydrogen, methanol, and carbon black.[15] LPG and still gas are used in the production of many petrochemicals including ethylene, propylene, vinyl chloride, and styrene.

The industry's energy consumption and intensity declined fairly steadily in the 1970s and 1980s (figure 2-10b). From 1974 to 1988, energy consumption fell by 13 percent and energy intensity fell by 31 percent. The central role played by natural gas for heat, power, and feedstocks in many chemical processes inhibited switching to alternate fuels during the gas supply curtailments and price rises during the 1970s.

PULP AND PAPER

The pulp and paper industry is the fourth largest energy consuming industry. In 1989, about 56 percent of the industry's energy demands were met by self-generated and residue fuels such as spent pulping liquor, hogged fuel, and bark. The proportion has risen since 1972, when self-generated and residue fuels met 40

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[13] Energetic, he., *Industry Profiles: petroleum,* prepared for U.S. Department of Energy, Office of Industrial Technologies, Report No. DE-AC01-87CE40762, December 1990.

[14] U.S. Department of Commerce, Bureau of the Census, op. cit., footnote 10.

[15] Estimates of the amount of natural gas used as feedstocks vary widely. DOE shows consumption at 540 trillion Btu in 1988 and 490 trillion Btu in 1985. U.S. Department of Energy, Energy Information Administration, *Manufacturing Energy Consumption Survey (MECS), Consumption ofEnergy, 1988* Report No. DOE/EIA-05 12(88), May 1991 and 1985 Report No. DOE/EIA-05 12(85), November 1988. The Gas Research Institute (GRI) shows the consumption in 1985 to be 643 trillion Btu, used to produce ammonia (368 trillion Btu), hydrogen (199), methanol (55), and carbon black (21). Gas Research Institute, *Industrial Natural Gas Markets: Facts, Fallacies and Forecasts*, op. cit., footnote 9.

percent of the industry's energy needs.[16] The pulp and paper industry is the leading cogenerator of electric power. About 40 percent of the industry's electricity demand is met with cogenerated fuel.[17] In 1990, purchased energy represented 5.8 percent of the industry's production costs.[18]

Unlike other sectors, the pulp and paper industry's energy consumption rose in the 1980s, because of growth in output. However, the industry's energy intensity continued its gradual decline in this period (figure 2-1Oc). From 1974 to 1988, energy consumption rose by 6 percent and energy intensity fell by 19 percent.

FOOD

The food and beverage processing industry, the fifth largest industrial energy consumer, includes facilities that produce meat, dairy, fruit, vegetable, grain, bakery, sugar, confectionery, fat, oil, and beverage products. Among the largest energy consumers are wet corn millers, beet sugar producers, and malt beverage brewers. The food industry uses energy primarily for separations processes. The use of boiling to concentrate food products from liquid streams is a particularly energy intensive process.[19] The principal fuels used in the food industry are natural gas for steam production and direct heating, electricity for motor drive, and coal for steam production. Self-generated electricity accounted for 7.5 percent of electricity demand in 1988.[20] Most of the cogenerating capacity is located at cane and beet sugar processors, wet corn millers, and malt beverages brewers.

In the 1970s and 1980s, the industry's energy consumption remained fairly steady and its intensity declined (figure 2-10d). From 1974 to 1988, energy intensity fell by 24 percent.

I Materials Production

The materials production group includes: steel (SIC 331), aluminum (SIC 3334), other primary metals (balance of SIC 33), cement (SIC 324), glass (SIC 321-323), and other ceramic products (SIC 325-329). It is the second largest industrial energy consuming sector, using 3.8 quads in 1988. The materials production industries are simpler than the process industries, particularly chemicals, in the sense that there are fewer processes and products. Also, the products tend to be low-value-added, commodity materials. Materials production is characterized by heavy use of direct process heat for activities such as metals heating, treating, melting, and smelting, ore agglomeration, lime and cement calcining, clay and brick firing, and glass melting, curing, and forming. Direct process heating consumes 42 percent of the energy used by this group. Most of the remaining energy is used for feedstocks (27 percent), steam production (10 percent), motor drive (9 percent), and electrolytic processing (8 percent).[21]

Coal and coke are the largest sources of energy in the materials production sector, accounting for 47 percent of the consumption in the sector overall and roughly 70 percent in the steel and hydraulic cement industries. Natural gas is next largest energy source with 32 percent of consumption. The remainder is accounted for by electricity (16 percent), petroleum (3 percent), and miscellaneous energy (2 percent).

16 Statistics from the American Paper Institute, Inc.

17 U.S. Department of Energy, 1988 MECS, op. cit., footnote 15.

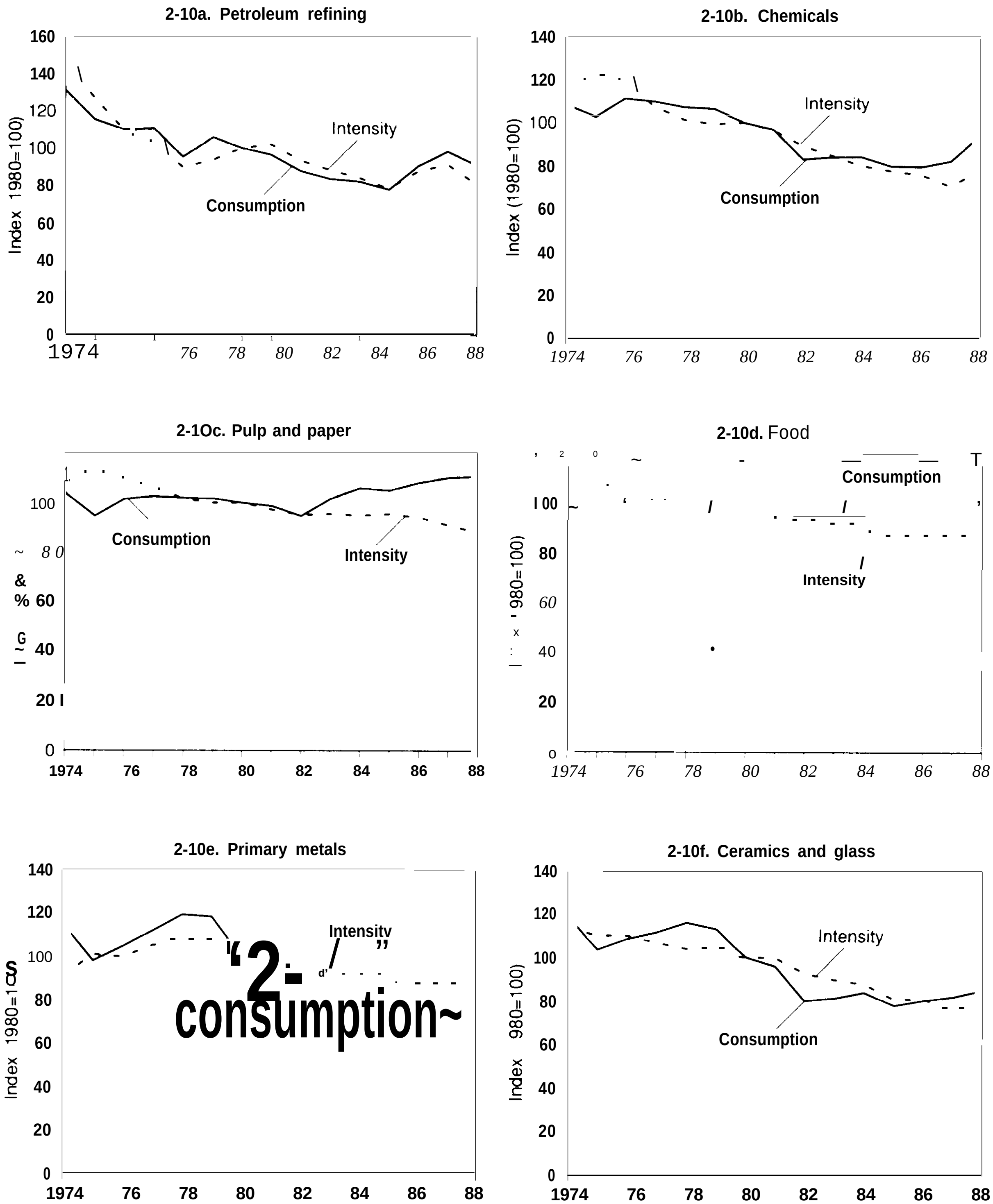
18 U.S. Department of Commerce, Bureau of the Census, op. cit., footnote 10.

19 Decision Analysis Corporation of Virginia, *Energy Consumption Patterns in the Manufacturing Sector*, prepared for U.S. Department of Energy, Energy Information Administration, Oct. 15, 1990.

20 U.S. Department of Energy, 1988 MECS, op.cit., footnote 15.

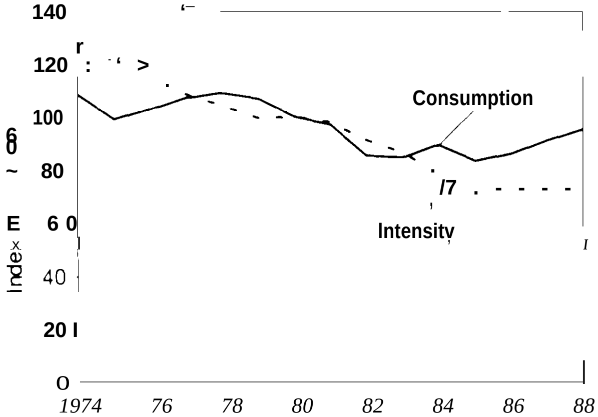
21 OTA, op. cit., footnote 12.

Figure 2-l&Energy Consumption and Energy Intensity of Industry Sectors, 1974-88

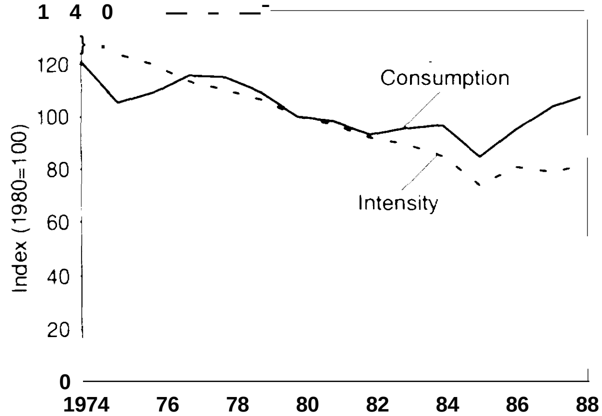


Energy Consumption and Energy Intensity of Industry Sectors, 1974-88-(Continued)

2-10g. Metals fabrication



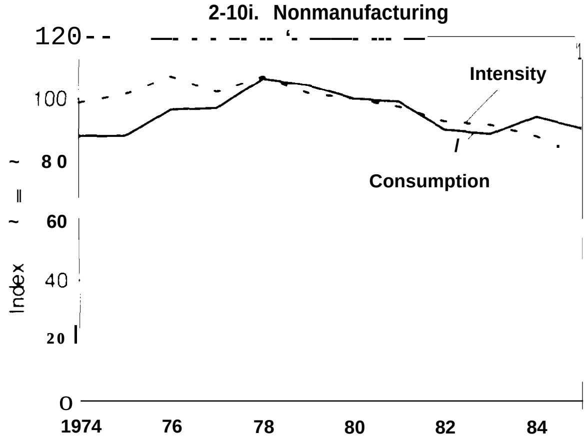
2-10h. Nonmetals fabrication



NOTE: Consumption and intensity data are based on offsite-produced energy used for heat and power.

SOURCES: U.S. Department of Commerce, Bureau of Labor Statistics, "Output and Employment database." Manufacturing sectors: U.S. Department of Energy, Energy Information Administration, Derived *Annual Estimates of Manufacturing Energy Consumption, 1974-1988,* Report No. DOE/EIA-0555(92)/3, August 1992. Nonmanufacturing sector: U.S. Department of Commerce, Office of Business Analysis, "National Energy Accounts database."

2-10i. Nonmanufacturing



PRIMARY METALS PRODUCTION

The steel industry dominates energy use in the primary metals group. Its principal energy source is coal, which is used to produce coke. Coke serves as both a fuel and feedstock in ironmaking processes. Its fuel function is to melt the iron ore pellets, and its feedstock role is to reduce iron oxide to pig iron. Coal and coke account for 69 percent of energy use in the steel industry. Electricity accounts for 7 percent of the industry's energy consumption, Electricity use has remained relatively steady over the last two decades, but its share of total energy consumption has grown because of increasing use of electric steelmaking processes.[22] Recently though, electric Steelmaking has not been growing. It has accounted for a steady 36 to 38 percent of U.S. raw steel production since 1986.[23]

Aluminum production is centered around the Hall-Heroult electrolytic reduction process. Aluminum facilities thus consume large amounts of electricity and are often the largest customers of their local utilities. Electricity accounted for 87 percent of the aluminum industry's energy use in 1988, and 26 percent of its production costs in 1990.[24] Aluminum is the largest electricity consuming industry.

22 Electricity met 5.1 percent of the industry's heat and power needs in 1970 and 9.4 percent in 1985, U.S. Department of Commerce, Office of Business Analysis, "National Energy Accounts database."

23 American Iron and Steel Institute, *Annual Statistical Report, 1991* (Washington, DC: 1992)

24 U.S. Department of Energy, 1988 MECS, op. cit., footnote 15 and U.S. Department of Commerce, Bureau of&z Census, op. cit., footnote 10.

The other metals category include primary copper, lead, and zinc producers, ferrous and nonferrous foundries, and nonferrous rolling and forging mills. Natural gas is the principal fuel in this group overall. However, lead production uses mostly coal, and zinc production, which is an electrolytic process, uses mainly electricity.

The primary metals industry's energy consumption declined sharply between 1979 and 1982, and has remained fairly steady in subsequent years (figure 2-1Oe). The industry's energy intensity declined gradually over this same period. From 1974 to 1988, energy consumption fell by 32 percent and energy intensity fell by 3 percent.

CERAMICS AND GLASS

Nonmetals companies, which include cement, glass, brick, tile, refractories, pottery, concrete, gypsum, and plaster, and cut stone producers, comprise the sixth largest industrial energy consuming group. For these industries as a group, natural gas—used to fire furnaces and kilns-is the principal fuel. However, the cement industry, the largest energy consumer of the group, primarily uses coal to fire its kilns. In the 1960s, cement producers used nearly as much natural gas as coal. After the frost oil crisis, the industry began phasing natural gas out. Gypsum producers also use mostly coal, and ready-mix concrete producers use mostly fuel oils in their processes.

The industry's energy consumption and intensity declined fairly steadily in the 1970s and 1980s (figure 2-10f). From 1974 to 1988, energy consumption fell by 28 percent and energy intensity fell by 32 percent.

H Metals Fabrication

The metals fabrication group includes: transportation equipment (SIC 37), fabricated metals (SIC 34), machinery (SIC 35), electrical equipment (SIC 36), instruments (SIC 38), and miscellaneous manufacturing (SIC 39). This group used 1.4 quads of energy in 1988. These industries generally engage in physical conversion of materials (e.g., cutting, forming, assembly) and are thus heavily reliant on motor-drive systems. Motor drive accounts for 31 percent of the group's energy consumption. Heat treating, drying, bonding, and other direct process heating operations associated with metals fabrication account for 32 percent of the energy used. The remaining energy is used primarily for steam production (19 percent) and space conditioning, lighting, and office equipment (10 percent).25

Natural gas is the largest source of energy in the metals fabrication sector, accounting for 45 percent of energy consumption. Electricity is the next largest energy source with 38 percent of consumption. The remainder is accounted for by coal (8 percent), petroleum (3 percent), and miscellaneous energy (3 percent).26

The industry's energy consumption and intensity declined fairly steadily from the mid-1970s until the mid-1980s (figure 2-10g). In subsequent years, energy consumption rose and energy intensity remained even. From 1974 to 1988, energy consumption fell by 13 percent and energy intensity fell by 43 percent.

~ Nonmetals Fabrication

The nonmetals fabrication group includes: lumber and wood (SIC 24), rubber and plastics (SIC 30), printing and publishing (SIC 27), furniture (SIC 25), apparel (SIC 23), and leather (SIC 31). This group is the smallest industrial energy consuming sector, using 0.9 quads of energy in 1988. The lumber and wood industry dominates energy use in the group. Like the metals fabrication group, the industries of this sector are heavily reliant on motor drive. Motor-drive accounts for 29 percent of the energy used by this group. These industries also use large

25 OTA, op. cit., footnote 12.

26 U.S. Department of Energy, 1988 MECS, op.cit., footnote 15.

amounts of heat, provided by both steam and direct process means. The lumber, wood, rubber, plastics, and leather industries use primarily steam heat. The printing, publishing, furniture, and apparel industries rely more heavily on direct process heat. Of the energy consumed by the overall group, steam accounts for 40 percent, and direct process heating accounts for 23 percent. The remaining energy is used primarily for space conditioning, lighting, and office equipment (5 percent) .27

Wood chips and bark are the largest sources of energy in the nonmetals fabrication sector, accounting for 30 percent of energy consumption. They are used primarily in the lumber and wood industry, but also in the furniture industry. Electricity is the second largest energy source, accounting for 29 percent of consumption, followed by natural gas at 27 percent. The remainder is accounted for by petroleum (7 percent), coal (2 percent), and miscellaneous energy (4 percent) .28

The industry's energy consumption and intensity declined fairly steadily from the mid-1970s until the mid- 1980s (figure 2-10h). In subsequent years, energy consumption rose and energy intensity remained even. From 1974 to 1988, energy consumption fell by 10 percent and energy intensity fell by 38 percent.

I Nonmanufacturing

The nonmanufacturing group includes: agriculture, forestry, and fishing (SIC 1,2,7,8,9), coal mining (SIC 12), metal mining (SIC 10), nonmetal mining (SIC 14), oil and gas extraction (SIC 13), and construction (SIC 15-17). Natural gas is the largest source of energy in the nonmanufacturing sector, accounting for 44 percent of energy consumption. It is used primarily as lease and plant fuel in oil and gas extraction. Asphalt, road tar, and road oil are the next largest energy sources with 18 percent of consumption. The remainder is accounted for by electricity (13 percent), fuel oil (13 percent), crude oil (6 percent), LPG (3 percent), and coal (3 percent) .29

The nonmanufacturing sector's energy consumption and intensity declined gradually steadily after the late 1970s (figure 2-10i). From 1978 to 1985, energy consumption fell by 14 percent and energy intensity fell by 23 percent.

ENERGY INTENSITY

Industrial energy use dampened in the last two decades, but the value of industrial output generally increased. As a result, industry's dependence on energy—as measured by its energy intensity—declined.[30]

Energy intensity is the amount of energy used to produce a unit of output. Usually, it is measured in Btu of energy per dollar of output or value added (contribution to gross domestic product) .31 From the 1960s until the first oil shock in 1974, industrial energy intensity remained relatively steady at 19,000 to 21,000 Btu per dollar of industrial output (constant 1990 $) (figure 2-1 1). Growth in energy use was directly coupled with growth in industrial output. From 1974 until 1986, efficiency improvements and sectoral structure changes caused industrial energy intensity to decrease by a third. Since 1986, energy intensity has remained between 13,000 and 14,000 Btu per dollar output (1990 $), suggesting that energy consumption has once again become directly coupled with industrial output, albeit at a lower level.

27 OTA, op. cit., footnote 12.

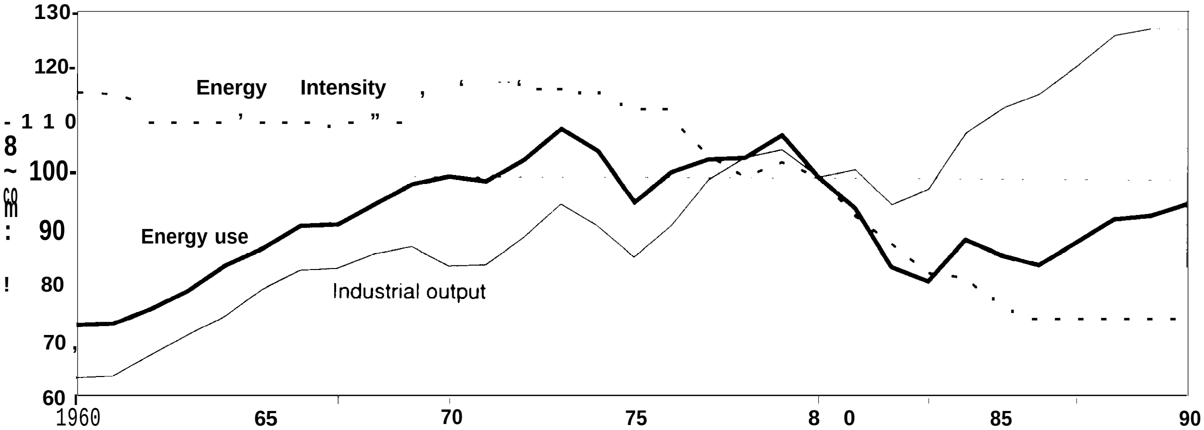
28 U.S. Department of Energy, 1988 MECS, op.cit., footnote 15.

29 U.S. Department of Commerce, op.cit., footnote 22.

30 Energy intensity measured in Btu of energy consumption per constant dollar of industrial output.

31 For some homogeneous industries, intensity can be measured in Btu per physical unit Of input or output. For example, petroleum 'frog intensity is measured in Btu per barrel of crude oil input, and steel industry intensity is measured in Btu per ton of finished steel output.

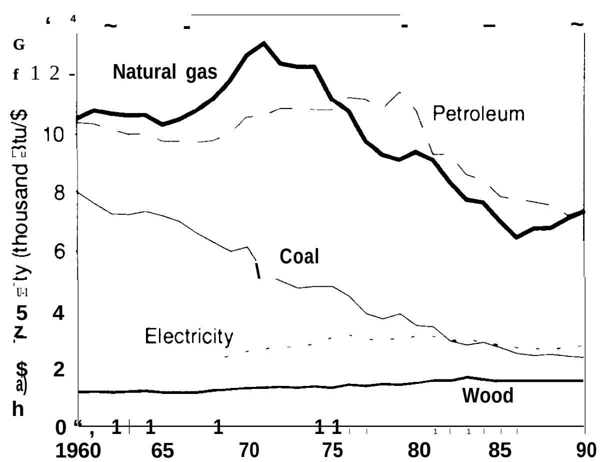
Figure 2-11—Industrial Output, Energy Consumption, and Energy Intensity, 1960-90



NOTE: In 1980, industrial energy use was 25.4 quads, gross product originating (output) was $896 billion, and energy intensity was 28,300 Btu/$ output. Energy consumption includes coal, natural gas, petroleum, wood, and electricity used for heat, power, electricity generation, and feedstock purposes; and excludes waste, geothermal, wind, photovoltaic, and solar thermal energy and electricity generation, transmission, and distribution losses. Gross product originating (output) data presented in the figure and used in intensity calculations are in constant dollars.

SOURCES: U.S. Department of Energy, Energy Information Administration, State Energy Data Report, *Consumption Estimates 1960-1990,* Report No. DOE/EIA-0214(90), May 1992 and *Annual Energy Review 1991,* Report No. DOE/EIA-0384(91), June 1992. Robert P. Parker, U.S. Department of Commerce, Bureau of Economic Analysis (BEA), "Gross Product by Industry, 1977-90," Survey *of Current Business,* May 1993 and BEA, "National Income and Product Accounts database."

Figure 2-12—Industrial Energy Intensity by Fuel 1960-90



NOTE: Gross product originating (output) data presented in the figure and used in intensity calculations are in constant dollars.

SOURCES: U.S. Department of Energy, Energy Information Administration, *State* Energy Data Report, *Consumption Estimates 1960-1990,* Report No. DOE/EIA-0214(90), May 1992 and *Annual Energy Review 1991,* Report No. DOE/EIA-0364(91), June 1992. Robert P. Parker, U.S. Department of Commerce, Bureau of Economic Analysis (BEA), "Gross Product by Industry, 1977-90," Survey of *Current Business,* May 1993 and BEA, "National Income and Product Accounts database."

The intensity of natural gas use increased until 1971, and then over the next 15 years fell by about 50 percent (figure 2-12). Shortages of natural gas contributed to the decline. In recent years, natural gas intensity has been rising again. Petroleum intensity has fallen 35 percent since 1979. Coal intensity has fallen steadily since 1960, but the rate of decline slowed in the mid- 1980s. Electricity intensity increased from 1958 to 1970 and then leveled out, partly because of increases in its price. In 1983, the intensity of electricity use surpassed that of coal use.

Efficiency and Structure

Energy intensity is dependent on energy efficiency and industrial structure. A decline in intensity may be the result of: 1) improved industrial processes and practices and/or 2) decreased production of energy-intensive products. For example, all of the following activities would decrease energy intensity:

- Investment by steelmakers in modern, efficient equipment;

- Shifts in the economy, away from steelmaking toward computer manufacturing;
- Changes in steel product lines, away from low-value steels toward thinner, stronger, higher-value steels; and
- Modifications in steel facilities, away from cokemaking toward coke importation.

The last example does not actually lower the energy intensity of steelmaking, but transfers the intensity to coke exporters.

Industries differ in energy intensity by a factor of 200 (figure 2-8), so a shift in output mix can have a significant effect on the energy intensity of the sector as a whole. Studies have shown that roughly one-half to two-thirds of the decline in manufacturing's energy intensity between the mid-1970s and mid-1980s can be attributed to energy efficiency improvements. The remaining portion of the decline can be attributed to a shift in the mix of output, with ''smokestack' industries declining relative to lighter manufacturing industries .32

Industrial energy intensity has fallen only slightly since the mid-1980s. Between 1985 and 1988, the energy intensity of the manufacturing sector declined by 5 percent. However, most of the decline was caused by structural shifts. Energy efficiency improvements for the manufacturing sector as a whole were negligible during this period.[33]

1 International Comparisons

Industry tends to be more energy intensive in the United States than in other industrialized countries (figure 2-13). This is not, however, direct evidence of inefficiency in U.S. industry. The differences in energy intensity result from variations in industrial structure, relative factor input prices, and technological efficiency.

The structural differences are evident at several levels. First, the United States has a high proportion of heavy, energy-intensive industries such as petroleum refining, chemicals, steel, and paper. Second, even within industries, the United States tends to encompass more of the energy-intensive processing stages. For example, the U.S. paper industry uses almost twice as much energy per dollar of output than does the Japanese paper industry. This disparity occurs partly because Japanese papermakers import much of their pulp, whereas U.S. papermakers produce most of their pulp themselves.

The relatively low price of energy in the United States is another factor encouraging the high energy intensity of U.S. industry. U.S. energy prices are generally among the lowest in the industrialized world (table 2-5). The low prices not only discourage the adoption of more energy efficient technologies and processes, but also encourage energy-intensive industries to locate in the United States.

Just as the aggregate intensity figures should not be taken as evidence of U.S. inefficiency, the structure and price arguments should not be construed as evidence that the United States is energy efficient. Comparing the industrial efficiencies of different countries is very complex because of the many business environment characteristics that define the efficient level of energy

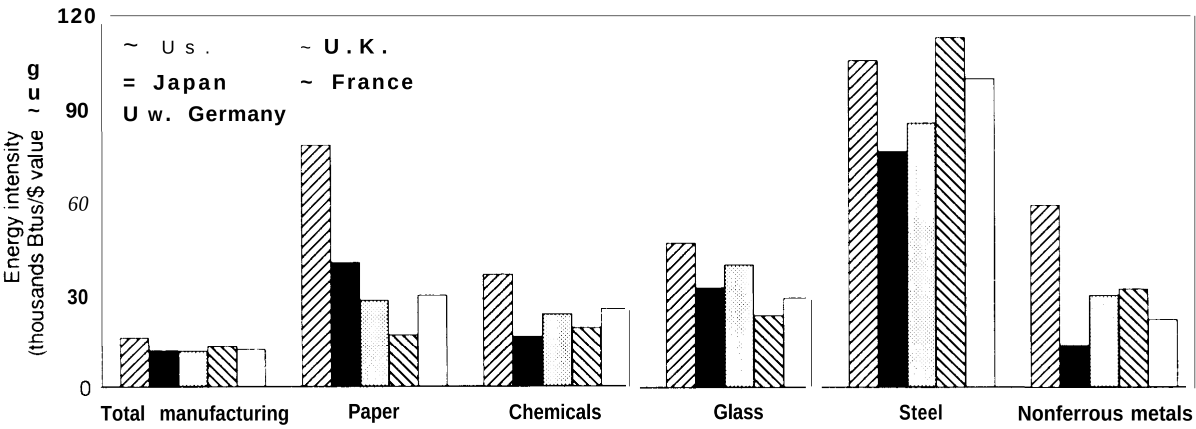
32 C. Doblin, ''Declining Energy Intensity in the U.S. Manufacturing Sector," *The Energy Journal, vol. 9, No. 2,* pp. 109-135, 1988. U.S. manufacturing sector, 1974-1980. Annual reduction in primary energy intensity caused by structure shifts (1.1 percent) and technology improvements (1.1 percent).

R. Marlay, "Trends in Industrial Use of Energy," *Science,* vol. *226,* pp. 1277-1283, 1984. U.S. mining and manufacturing sectors, 1973-1982. Annual avoided growth in energy use caused by slower economic growth (1.4 percent), structure shifts (1.0 percent) and technology improvements (1.2 percent).

U.S. Congress, Office of Technology Assessment, *Energy Use and the U.S. Economy,* OTA-BP-E-57 (Washington, DC: U.S. Government Printing Office, June 1990). Entire U.S. economy, 1972-1985. Avoided growth in primary energy use caused by structure shifts (9.5 quads) and technology improvements (15.4 quads).

33 J. L. Preston, R. K. Adler, and M. A. Schipper, U.S. Department of Energy, Energy Information Administration, "Energy Efficiency in the Manufacturing Sector, ' *Monthly Energy Review,* December 1992.

Figure 2-13-industrial Energy Intensity of Selected Countries by Industry Sector, 1988



SOURCE: Data obtained from International Energy Studies Group at Lawrence Berkeley Laboratory, Berkeley California.

use. Proving that one country is more or less efficient than another given their respective business environments is extremely difficult. Such proof would require comparisons of specific processes and business conditions in different countries. All that can be justifiably concluded from current data is that, compared with other industrialized nations, the United States is not as energy inefficient as it first appears.

OUTLOOK

Forecasting industrial energy use and the possible effects of adopting energy-efficient technologies is difficult for a variety of methodological reasons. Industrial processes are complicated, and there are many efficient technologies to consider. Also, few technologies are applicable to all industries in all instances. Most have limited applicability, for site-specific or process-specific reasons. Moreover, efficiency is intimately tied with process yields, which are themselves changing. Nevertheless, several recent studies have forecasted industrial energy consumption under various policy climates. Among them are:[34]

- U.S. Department of Energy, Energy Information Administration, *Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy*, December 1990;
- U.S. Department of Energy, *National Energy Strategy: Technical Annex 2, Integrated Analysis Supporting The National Energy Strategy: Methodology, Assumptions and Results, 1991/1992;*
- Alliance to Save Energy, American Gas Association, and Solar Energy Industries Association, *An Alternative Energy Future, April 1992;*
- Alliance to Save Energy, American Council for an Energy-Efficient Economy, Natural Resources Defense Council, and Union of Concerned Scientists in consultation with

34 Other studies that have forecasted various aspects of industrial energy use include:

- Gas Research Institute, *Industrial Natural Gas Markets: Facts, Fallacies and Forecasts,* op. cit., footnote 9;
- Gas Reseach Institute, *Annual Baseline Projection Data Book (Chicago, IL: Gas* Research Institute, annual);
- Electric Power Research Institute, *Efficient Electricity Use: Estimates of Maximum Energy Savings, EPRI CU-6746 (Palo* Alto, CA: Electric Power Research Institute, March 1990); and
- Oak Ridge National Laboratory, *Energy Efficiency: How Far Can We Go?* ORNL/TM-1 1441 (Springfield, VA: National Technical Information Service, January 1990).

Table 2-5-international Industrial Energy Prices, 1991

	United States	Japan	Germany	France	United Kingdom	Canada	Measurement
Electricity	$0.049	$0.136	$0.088	$0.054	$0.071	$0.039	$/kWh
Natural gas	2.63	11.04	5.23	3.94	4.19	2.26	$/thousand cf
Petroleum							
Light fuel oil	0.70	1.02	1.02	NA	0.84	0.72	$/gallon
Heavy fuel oil	0.30	0.86	0.49	0.41	0.44	0.37	$/gallon
Coal							
Steam	33.51	63.29	165.49	91.84	69.82	54.92[a]	$/short ton
Metallurgical	48.83	56.10	56.45	58.32	NA	51.60[a]	$/short ton

NOTE: Prices include taxes.

a Coal prices for Canada are for 1989.

SOURCE: Organization for Economic Cooperation and Development, International Energy Agency, *Energy Prices* and *Taxes, Third Ouarter 1992.*

the Tellus *Institute, America' s Energy Choices: Investing in a Strong Economy and a Clean Environment: Technical Appendixes,* 1992; and

- U.S. Congress, Office of Technology Assessment, *Changing by Degrees: Steps to Reduce Greenhouse Gases, February* 1991.

This section discusses the results of these studies.

~ Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy

This study was prepared by the Energy Information Administration (EIA) of DOE. It includes three forecasts: a Reference case, a High Conservation excursion, and a Very High Conservation excursion. The Reference case represents a continuation of historical energy consuming and conservation patterns as related to energy prices and the value of industrial sector output. The conservation excursions assume greater use of cost-effective technology in new, replacement, and retrofit markets.

The key assumptions in the forecasts are industrial output, energy prices, and energy intensity. All three cases embody the same growth rates for industrial output and the same projections for energy prices. Gross national product (GNP) is forecasted to grow in real terms, 2.5 percent per year during 1988 to 2000,2.3 percent during 2000 to 2010, and 1.8 percent during 2010 to 2030. Growth in output varies by industry, ranging from 0.2 percent per year for petroleum refining to 3.7 percent for metal durables (table 2-6). Prices for petroleum and natural gas are assumed to increase rapidly until 2010, and then slow somewhat during 2010 to 2030. For electricity and coal, prices are expected to increase slowly until 2010, and after that, grow faster for coal and remain almost constant for electricity .35

35 *Projected* percent per year increases in energy prices are:

	1988-2010	2010-2030
Natural gas	3.7	1.1
Residual fuel oil	4.6	1.2
Distillate fuel oil	3.0	0.9
LPG	1.9	0.9
Motor gasoline	1.9	0.6
Steam coal	0.9	1.5
Metallurgical coal	0.8	1.6
Electricity	0.4	0.1

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Table 2-6—Forecasts of Industrial Growth Rates (percent per year)

	U.S. Department of Energy Energy information Administration		Americans Energy Choices	
	1988-2010	2010-2030	1988-2010	2010-2030
Petroleum refining	0.2	0.0	-0.6	-0.3
Chemicals	3.0	1.9	0.8	0.8
Primary metals	1.3	0.4	-0.6	-0.3
Pulp and paper	2.4	1.6	0.6	0.3
Ceramics and glass	1.9	1.9	-0.5	-0.3
Food	1.7	1.9	0.3	0.3
Metal durables	3.7	2.2	2.6	1.4
Other manufacturing	2.3	1.4	1.2	0.8
Total manufacturing	2.8	1.9.	1.6	1.0
Nonmanufacturing	1.5	1.8	1.5	1.8
Total industry	2.5	1.8	1.6	1.2

NOTE:These growth rates are assumed to prevail in all scenarios of their respective studies, except that the petroleum refining industry activity differs in each scenario in the America's Energy Choices study, because oil consumption differs (the rates shown are for the reference case only).

SOURCE: U.S. Department of Energy, Energy Information Administration, *Energy Consumption and Conservation Potential.' Supporting Analysis for the National Energy Strategy,* Report No. SR/NES/90-02, December 1990. Alliance to Save Energy, American Council for an Energy-Efficient Economy, Natural Resources Defense Council, and Union of Concerned Scientists in consultation with the Tellus Institute, *America's Energy Choices: Investing in a Strong Economy and a Clean Environment: Tehnical Appendixes* (Cambridge, MA: Union of Concerned Scientists, 1992).

Energy intensity is the main factor that varies in the three forecasts. In the Reference case, intensity is assumed to decline between 0.7 and 2.0 percent per year in the various industries during 1990 to 2010 (table 2-7). The chemicals industry is expected to have the largest decline in intensity and the petroleum industry is expected to have the smallest. In the High Conservation excursion, intensity is assumed to decline an average of 0.5 percentage points per year faster than the Reference case. In the Very High Conservation excursion, intensity is assumed to decline 0.25 percentage points per year faster than in the High Conservation case in every industry.

Industrial energy consumption is forecasted to grow to 30.7 quads by 2010 and 36.5 quads by 2030 in the Reference case (figure 2-14). This represents an average growth rate of 0.9 percent per year. The fuel intensity declines and electricity intensity increases throughout the forecast period. In the High Conservation excursion, 2010 and 2030 energy consumption levels are projected to be 7 to 10 percent lower than in the Reference case. In the Very High Conservation excursion, consumption levels are additional 4 to 7 percent lower.

H National Energy Strategy, First Edition 1991/1992

This DOE report projects that under the current policy environment, industrial energy use will grow to levels slightly higher than those in the previous report (31.1 quads in 2010 and 38.0 quads in 2030). With the full implementation of the National Energy Strategy (NES), consumption levels are projected to be 5 to 11 percent lower than the Base case in 2010 and 2030.[36]

36 DOE published its National Energy Strategy (NES) in February 1991 to lay ''the foundation for a more efficient, less vulnerable, and environmentally sustainable energy future. ' For the industrial sector, the NES proposed to: 1) increase industrial process efficiency research and development (R&D), 2) increase industrial waste minimization R&D, 3) reform waste regulations, and 4) expand and develop energy auditing capabilities.

Table 2-7—Forecasts of Rates of Energy Intensity Decline (percent per year)

	U.S. Department of Energy Energy information Administration			America's Energy Choices			
	Reference case	High conservation excursion	Very high conservation excursion	Reference case	Market case	Environmental case	Climate stabilization case
Petroleum refining	0.7	0.9	1.2	0.2	1.3	1.3	2.2
Chemicals	2.0	2.0	2.3	1.8	2.4	2.9	2.3
Primary metals	1.0	2.0	2.3	1.0	2.1	3.1	3.7
Pulp and paper	1.1	2.1	2.4	1.2	1.7	2.0	2.1
Ceramics and glass	1.4	1.9	2.2	1.3	2.2	3.3	3.6
Food	0.8	1.6	1.9	0.8	1.9	4.3	4.5
Metal durables	0.8	1.4	1.7	0.2	1.6	2.7	2.8
Other manufacturing	0.8	1.6	1.9	0.1	1.4	1.4	1.4
Agriculture	0.8	1.3	1.6	0.9	1.6	2.1	2.5
Mining	0.8	1.3	1.6	0.2	1.4	1.8	1.8
Construction	0.8	1.3	1.6	0.8	1.5	2.0	2.4
Feedstocks	1.4	1.4	1.6	0	0	0	0

SOURCE: U.S. Department of Energy, Energy Information Administration, *Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy,* Report No. SR/NES/90-02, December 1990. Alliance to Save Energy, American Council for an Energy-Efficient Economy, Natural Resources Defense Council, and Union of Concerned Scientists in consultation with the Tellus Institute, *America's Energy Choices: Investing in a Strong Economy and a Clean Environment: Technical Appendixes* (Cambridge, MA: Union of Concerned Scientists, 1992).

I An Alternative Energy Future

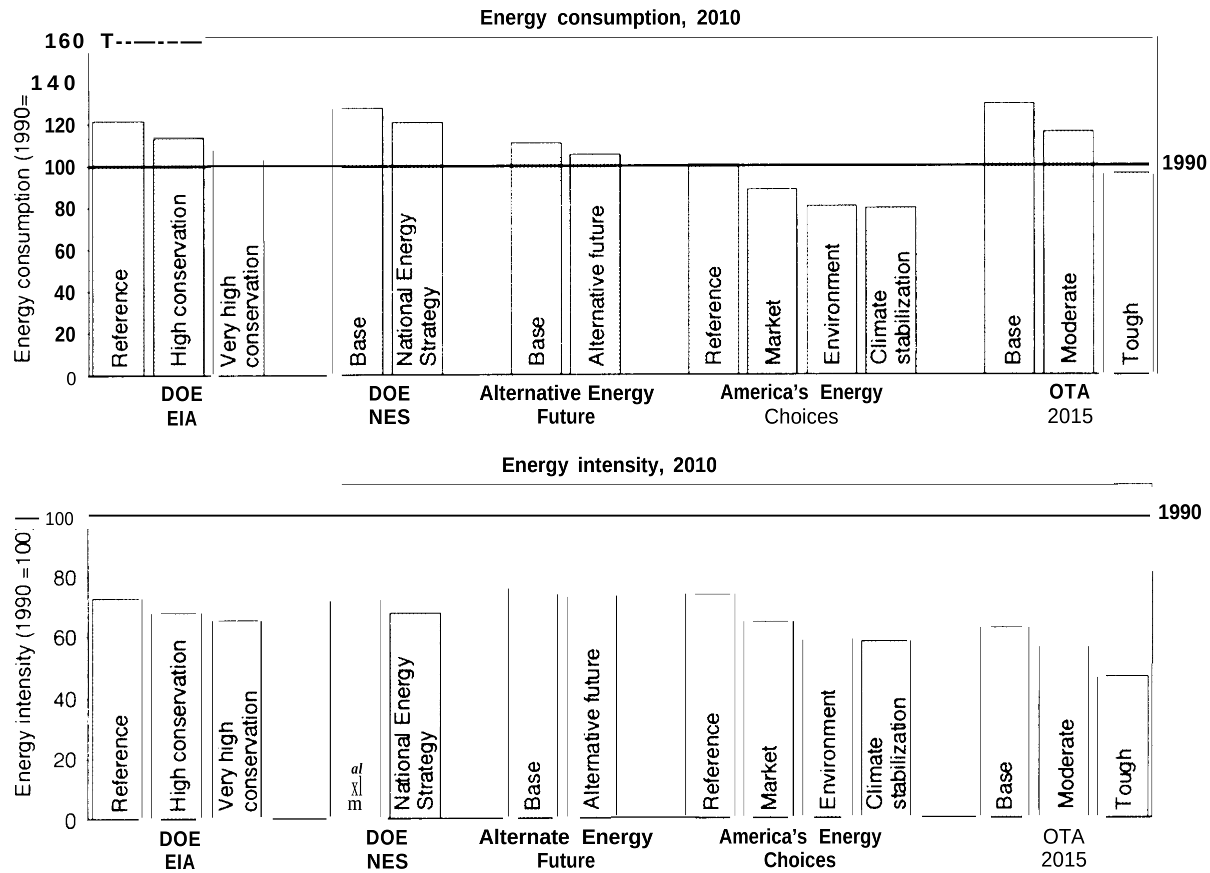
This study was written by the Alliance to Save Energy, the American Gas Association, and the Solar Energy Industries Association. It examines a free market approach to energy use with an emphasis on efficiency and clean fuels in legislation, regulation, and research and development (R&D) programs. New government intervention in the energy marketplace and significant new policy initiatives are specifically excluded. The Alternative Energy Future assumes:

- Continued improvement in efficiency of deployed energy technologies, resulting from competitive forces as well as from reallocated R&D to natural gas, renewable, and efficiency technologies;
- Continued vigorous expansion of utility Integrated Resource Plans (IRPs) and passage of the IRP portion of National Energy Strategy legislation; and
- Elimination of State and Federal legislative and regulatory biases that discourage energy efficiency and encourage the use of carbon-intensive fossil fuels (e.g., mandatory scrubber requirements).

In the Base case, energy consumption grows at 0.5 percent per year and reaches 27.3 quads in 2010, about 11 percent lower than the EIA Reference case levels. Renewable, electricity, and natural gas use increase, and coal and petroleum use decrease. The efficiencies of conventional applications rise, but are offset to some extent by increasing use of cogeneration and independent power plants. Energy intensity declines at 1.4 percent per year, from about 14,800 Btu per dollar of industrial output in 1990 to 11,200 Btu per dollar of output in 2010 (with output measured in constant 1990 dollars).

In the Alternative Energy Future, energy consumption grows at a slower rate, 0.3 percent per year, and reaches a level that is 5 percent lower than the Base case. There is greater use of renewable such as waste byproducts and solar power. Efficiency increases result from improved process controls, increased capture of waste heat, improvements in production techniques, and other conservation measures. Energy intensity falls at an average rate of 1.6 percent per year to reach 10,800 Btu per dollar of output in 2010. The efficiency gains in the Alternative Energy Future

Figure 2-14-Projections of Industrial Energy Consumption and Energy Intensity, 2010 and 2030



are somewhat greater than in the Base case, but are less than those achieved in the early 1980s.

fl America's Energy Choices: Investing in a Strong Economy and a Clean Environment

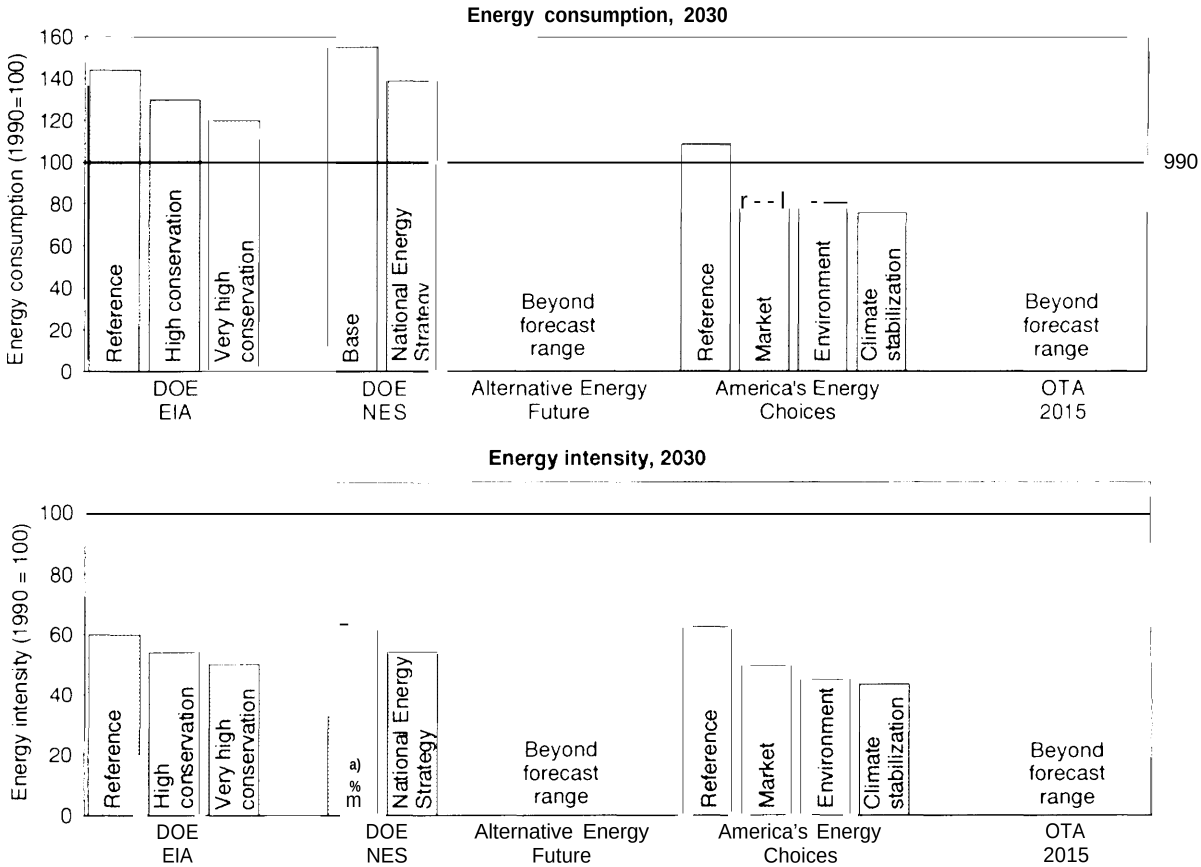
This study was prepared by the Alliance to Save Energy, the American Council for an Energy-Efficient Economy, the Natural Resources Defense Council, and the Union of Concerned Scientists in consultation with the Tellus Institute. It examines scenarios that are generally more proactive and interventionist than the other studies. Four policy scenarios are outlined: a Reference case, a Market case, an Environmental case, and a Climate Stabilization case.

Industrial production levels are the same in all four scenarios, except in the case of petroleum refining. The factors varied in the scenarios are energy intensity, cogeneration, and fuel switching.

The overall GNP growth is the same as in the EIA projections.[37] However, this study incorporates: 1) a larger shift from the manufacturing sector toward the service sector and 2) greater movement from energy-intensive basic industries toward less intensive fabricating and assembly industries (table 2-6). Annual growth in total industrial output is 0.9 percentage points lower during 1988 to 2010 than in the EIA study. The annual growth rates among the various manufac-

37 The energy price assumptions are also very similar to those in the EIA study.

Figure 2-14—(Continued)



NOTE: The first year for the America's Energy Choices projection was 1988. The first year for the OTA projection was 1987. For this figure, the first year energy consumption and intensity data of these two studies were interpolated to 1990. The projections on the left cover 1990 to 2010, except that the OTA study covers 1990 to 2015. The projections on the right cover 1990 to 2030.

KEY: Labels within bar refer to different policy cases or scenarios presented in the studies.

SOURCE: DOE EIA: U.S. Department of Energy, Energy Information Administration, *Energy Consumption and Conservation Potential.' Supporting Analysis for the National Energy Strategy,* Report No. SR/NES/90-02, December 1990. DOE NES: U.S. Department of Energy, *National Energy Strategy: Technical Annex 2, Integrated Analysis Supporting The National Energy Strategy: Methodology, Assumptions and Results,* Report No. DOE/S-0086P, 1991/1992. Alternative Energy Future: Alliance to Save Energy, American Gas Association, and Solar Energy Industries Association, *An Alternative Energy future,* April 1992. America's Energy Choices: Alliance to Save Energy, American Council for an Energy-Efficient Economy, Natural Resources Defense Council, and Union of Concerned Scientists in consultation with the Tellus Institute, *America's Energy Choices: Investing in a Strong Economy and a Clean Environment: Tehnical Appendixes* (Cambridge, MA: Union of Concerned Scientists, 1992). OTA 2015: U.S. Congress, Office of Technology Assessment, *Changing by Degrees:* Steps *to Reduce Greenhouse Gases, OTA-O-482* (Washington, DC: U.S. Government Printing Office, February 1991).

turing industries are 0.8 to 2.4 percentage points lower than the corresponding EIA rates. In the 2010 to 2030 period, the discrepancies between the studies are smaller, but still considerable.

The Reference case reflects current policies, practices, and trends. Energy intensity is assumed to decline among the various industries at rates between 0.2 and 1.8 percent per year during 1990 to 2010 (table 2-7). In general, this case embodies less technological change than the EIA Reference case, as reflected by the generally lower rates of energy intensity decline. In 2010 to 2030, the reduction in intensity becomes faster in the chemicals and metal durables industries and slower in the paper, nonmetals production, agri-culture, and construction industries. Of particular note in this period are the intensity increases in the petroleum refining and the ''other' manufacturing industries.

Energy consumption in the Reference case is forecasted to grow slightly and then return to 25.1 quads in 2010, about 18 percent lower than the EIA Reference case level. Afterwards, consumption grows at 0.4 percent per year and reaches 27.3 quads in 2030, which is 25 percent below the EIA projection.

The other three scenarios are designed to deliver the same level and quality of energy services as the Reference case, but to do so at lower cost and with less environmental damage. They incorporate greater end-use energy efficiency, efficient new power supplies, infrastructure changes, and renewable energy investments.

The Market case makes use of cost-effective energy-efficiency and renewable energy technologies, assuming moderate market penetration rates, with no accounting for environmental or security costs beyond those embodied in current trends and policies (e.g., the Clean Air Act). It assumes minimization of the costs of energy services to consumers. In most industries, the rates of energy intensity reduction are similar in magnitude to the EIA's Very High Conservation excursion (table 2-7).

The Environmental case employs additional energy-efficiency and renewable energy resources to the extent justified by the environmental and security costs of fossil fuels. It also incorporates adoption of externality values in energy pricing.

The Climate Stabilization case assumes compliance with carbon dioxide (CO2) emissions targets consistent with an effective international program to limit global warming (a 25-percent reduction in U.S. $CO2_z$ emissions by 2005 and at least a 50 percent reduction by 2030).

Energy consumption levels in Market, Environment, and Climate Stabilization cases are projected to fall throughout the forecast period. In the Market case, energy use is 12 percent lower than in the Reference case in 2010 and 21 percent lower in 2030. Consumption levels in the Environment and Climate Stabilization cases are both about 20 percent below the Reference case in 2010 and 29 percent lower in 2030.

R Changing by Degrees: Steps to Reduce Greenhouse Gases[38]

The Office of Technology Assessment developed an energy technology model to track the effects of various technical options to reduce $C0_2$ emissions. Three scenarios were run with the model—Base case, Moderate, and Tough—corresponding to different levels of commitment to emissions reduction.

In the Base case or ''business-as-usual" scenario, no new policies are adopted, and industrial production is projected to increase 2.7 percent per year. 39 The Moderate scenario assumes product and process changes that reduce the energy intensity of the four biggest energy-using industries (paper, chemicals, petroleum refining, and primary metals) by 1.2 to 1.8 percent per year. The scenario also includes motor and lighting conservation measures and increased use of cogeneration.

The Tough case assumes that equipment stocks (e.g., boilers, motors, etc.) are replaced 5 years sooner than they normally would be. In addition, the energy intensities of the four largest industrial energy users decline between 2.3 and 4.3 percent per year (equivalent to the rate of decline experienced during 1980 to 1985). Other industries are assumed to experience an additional energy intensity reduction of 0.5 percent per year compared to the Base case. Cogeneration is assumed to provide 61 gigawatts in 2015 and meet 90 percent of new industrial steam demand. New, more efficient cogeneration technologies, such as

38 The figures in this discussion differ from the those in original text, because a different energy accounting system is used. Also, nOte that the final forecast year (2015) differs from the other studies.

39 Based on the Gas Research Institute, *Annual Baseline Projection* Book (Chicago, IL: Gas Research Institute, 1988).

intercooled steam-injected gas turbines (ISTIG), are assumed to account for about half of the new gas-fired cogeneration after 2005.

In the Base case, energy use is projected to increase 29 percent from 1990 to 2015. Application of technologies that are currently available and cost-effective on a life-cycle basis (the Moderate scenario) result in energy consumption levels in 2015 that are still about 16 percent above 1990 levels. Only in the Tough scenario, where technologies are employed that are either currently expensive or not expected to be commercially available in the next decade, does energy consumption drop below the 1990 level by 2015. In all three scenarios energy use grows at a slower rate than industrial production, so industrial energy intensity falls by between 37 percent (Base case) and 54 percent (Tough case) from 1990 to 2015,

I Summary

Energy consumption in 2010 varies from O to 29 percent above 1990 levels in the studies' Base/Reference cases (figure 2-14). The least vigorous policy scenarios in each study reduce consumption by 5 to 12 percent from their respective Base/Reference cases. The more ambitious policy scenarios achieve energy reductions of 10 to 26 percent below the Base/Reference cases. In 2030, the Base/Reference levels vary from 9 to 55 percent above 1990 levels, and the policy cases reduce consumption by 10 to 31 percent.

The differences in Base/Reference case energy consumption projections among these studies result primarily Ii-em dissimilar assumptions about industrial output. Industrial growth rates vary among the studies from 1.6 to 2.9 percent per year during 1990 to 2010, with slightly lower overall growth rates during 1990 to 2030. The energy intensity assumptions vary much less among the studies. Energy intensities are assumed to decline at 1.4 to 1.5 percent per year during 1990 to 2010 (except in the OTA study, which projects intensity to decrease at 1.8 percent per year) and at 1.2 to 1.3 percent per year during 1990 to 2030. The studies vary, however, in how they achieve these intensity reductions. For example, the EIA study relies more heavily on efficiency improvements and the America's Energy Choices study relies more on shifts in industrial structure.

The studies generally kept industry output growth rates and industrial structure constant among their scenarios. Therefore, differing assumptions about efficiency and conservation efforts are reflected mostly in the policy cases.