Chapter 6

The Manufacturing Sector

Photo Credit: Sun Oil Co.

CONTENTS

Boxes

Figures

Tables

Chapter 6

The Manufacturing Sector

INTRODUCTION

Manufacturing is a diverse sector of the U.S. economy, consisting of a heterogeneous group of industries that employ a wide array of technologies to produce everything from aircraft to toy dolls. Because of this diversity, a somewhat different set of policies is needed to address this economic sector than those discussed for other sectors such as transportation or buildings. This chapter explores manufacturings energy use and emissions, the major emissions-contributing industries, scenarios for the future, and policies that could effect the future.

OVERVIEW

Manufacturing accounts for about 30 percent of all energy consumed in the United States, and 80 percent of industrial energy use (51a). (Agriculture, mining, and construction account for the remaining 20 percent.) About one-third of U.S. carbon dioxide (CO_2) emissions result from all industrial activity. Due to data limitations, this chapter uses data for the broader category of industry as a proxy for that of the manufacturing sector.

Onsite combustion of fossil fuels and biomass for heat and power account for about half of industrial emissions, and purchased, fossil-fuel generated electricity accounts for most of the remainder. Some additional greenhouse gases are also released to the atmosphere as byproducts of manufacturing processes. For example, CO_2 is released during cement manufacture; chlorofluorocarbons (CFCs) are emitted from industrial solvents used in the electronics industry. Such noncombustion processes probably account for about 2 percent of U.S. greenhouse gas emissions. This chapter is principally concerned with energy-related emissions and the potential for their reduction.

Energy *use in* manufacturing can be changed in three ways:

1. by reducing the amount of energy consumed,
2. by switching to energy sources that emit lessor no greenhouse gases, and
3. by changing the mix of industries and products within the manufacturing sector.

By and large, policies for reducing greenhouse gas emissions from manufacturing focus on the frost two strategies. Macroeconomic policies such as trade or monetary policies tend to affect the industrial makeup of the manufacturing sector.

PAST AND PRESENT EMISSIONS AND ENERGY USE

U.S. manufacturing consumed over 17.5 quadrillion Btu's (quads) of fossil fuel and electricity in 1985 (see table 6-l), about one-quarter of the economy-wide total. This total would be 24 percent higher if the energy consumed in electricity generation and transmission were included (56).

Industrial energy consumption and electricity generation losses accounted for about 32 percent of U.S. CO_2 emissions. Nearly a third of these emissions came from electricity used to power machines and electrolytic processes. Over a quarter of the emissions came from process steam and a fifth came from process heat (see figure 6-l).

Although industry uses significant energy, its consumption relative to that of other sectors has diminished over time. In 1960, the industrial sector used 46 percent of all *energy* consumed in the United States (56). By 1980, industry's share of energy use had fallen to 40 percent, and in 1989 it had slipped to 36 percent (56). Some of this decline can be attributed to energy efficiency improvements within industry and to growth in the building and transportation sectors.

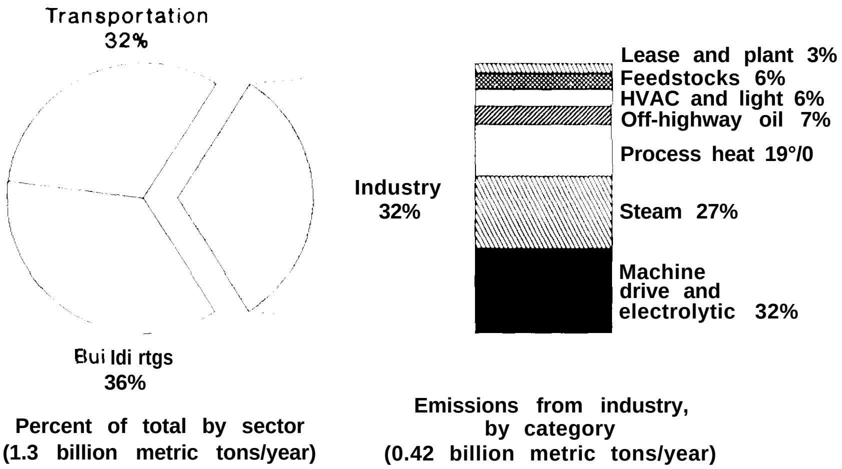
Table 6-l—Manufacturing's Use of Energy in 1985 (quadrillion Btu's)

Total fuel consumption	13.6
Total purchased fuels and electricity	9.7
Fuel byproduct (i.e., coke gas)	1.1
Process byproducts (i.e., wood chips)	2.8
Raw material (feedstock) inputs	5.0
Less fuel byproducts	(1.1)
Total primary energy consumption	17.5

NOTE: The Department of Energy does not account for generation and distribution losses associated with the production of electricity in these estimates of energy use.

SOURCE: U.S. Department of Energy, Energy Information Administration, *Manufacturing Energy Consumption Survey: Consumption of Energy, 1985,* DOE/EIA-0512(85) (Washington, DC: 1985).

Figure 6-1-Contribution of Industry CO_2 Emissions in 1987



SOURCE: Office of Technology Assessment, 1991.

Within industry, the manufacturing sector also has changed significantly in the recent past. From the 1950s through about 1972, the energy intensity of manufacturing (the energy used to produce a dollar's worth of output) was relatively flat (see figure 6-2). Thus, growth in manufacturing seemed to be directly coupled to growth in energy use.[1] Since 1972, however, the economy has suffered two unanticipated energy price shocks. In addition, legislation to control energy-related pollution was enforced and many of the biggest manufacturing firms experienced rapidly declining demand for their products (30). As a result of efficiency improvements and rising fuel prices, the energy intensity of manufacturing fell by more than a third from 1972 to 1985, with coal and oil intensities falling by almost 40 and 50 percent, respectively (33) (see figure 6-3). Shortages of natural gas after 1972 contributed to a 50 percent drop in energy intensity in manufacturing between 1971 and 1985 (33).

The electricity intensity of manufacturing increased rapidly from 1958 to 1970 and then, partly because of a rise in the price of electricity, began to level out (33). At 1987 average prices, it cost almost five times as much to use electricity as natural gas to provide equivalent heating value. Manufacturers thus use electricity not as a simple substitute for fuel, but to perform functions that require electricity or in specific processes where the overall efficiency of electricity is much higher than that of fuel. This illustrates that while different forms of energy can be discussed in terms of a common unit, Btu's, their utility for specific uses varies (20).

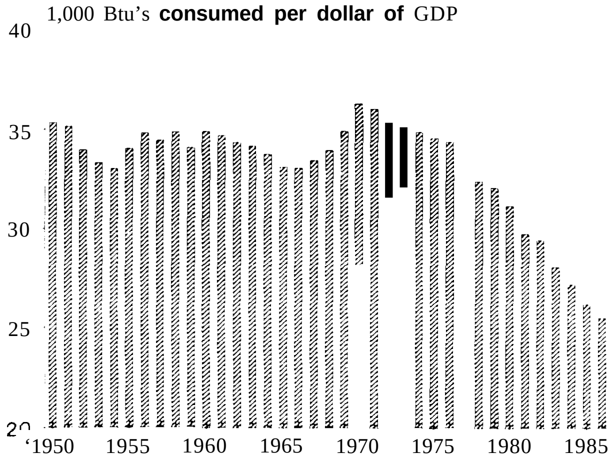
Because industries within the manufacturing sector differ in energy intensity by more than a factor of 10 (see table 6-2), a shift in output mix can have a significant effect on the energy intensity of the sector as a whole. In fact, roughly one-third to one-half of the decline in manufacturing's energy intensity between 1972 and 1985 can be attributed to a shift in the mix of output, with ''smokestack' industries like steel declining relative to lighter manufacturing industries like electronics (7, 27).

Our manufacturing sector's contribution to climate change is larger than these measures indicate. The United States now imports large amounts of energy-intensive manufactured products, including cars and steel. The energy embodied in these goods does not enter into U.S. energy intensity calculations, nor is it included in measures of our dependence on foreign energy (44). Nonenergy imports have doubled (as a percentage of GNP) since 1970, increasing the need to account for the energy they represent.

Such accounting can be done by assuming that all nonenergy imports can be made domestically at the same price using a similar mix of inputs as their domestic counterparts. When this is done for 1985 nonenergy imports, U.S. use of imported energy rises by over 50 percent, from 13 to 20 quads (see

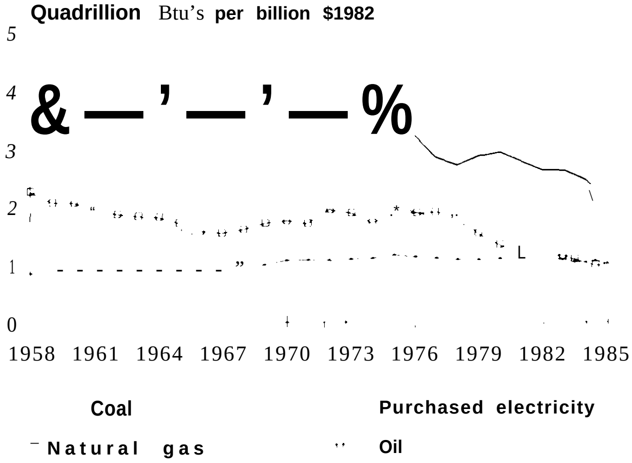
[1]Some analysts argue that a strong link still exists (6).

Figure 6-2—U.S. Energy Intensity: Energy Consumption Per Dollar of Gross Domestic Product



SOURCE: U.S. Congress, Office of Technology Assessment, *Energy Use and the U S Economy, OTA-BP-E-57* (Washington, DC: U.S. Government Printing Off Ice, June 1990).

Figure 6-3—Manufacturing Consumption of Energy for Heat and Power



SOURCE: M. Ross, "Industrial Energy Conservation," *Natural Resources Journal* 24(2):369, April 1984.

Table 6-2—Ranking of 1985 Manufacturing Energy Intensities (thousand Btu's per constant 1980-dollar value of shipments)

Stone, clay, and glass products	16.6
Primary metal industries	14.6
Paper and allied products	13.9
Chemicals and allied products	12.4
Textile mill products	4.8
Petroleum and coal products	4.4
Rubber and miscellaneous plastics	3.1
Food and kindred products	2.7
Fabricated metal products	2.3
Furniture and fixtures	1.6
Other manufacturing	1.4
Electrical and electronic equipment	1.2
Instruments and related equipment	1.2
Transportation equipment	1.1
Printing and publishing	0.9
Machinery, except electrical	0.9
All manufacturing	4.4

SOURCE: U.S. Department of Energy, Energy Information Agency, *Manufacturing Energy Consumption Survey: Changes in Energy* Efficiency 1980-1985, DOE/EIA-0516(85) (Washington, DC: January 1990), table ES1, p. viii.

figure 6-4).[2] While the energy embodied in U.S. exported products stayed relatively steady in the early 1980s, the energy embodied in imported products increased as the U.S. trade deficit deepened (see figure 6-4). The trade balance has improved somewhat since 1985 and so presumably net imports of embodied energy have declined.

Recent Changes in Energy Use[3]

Total energy use in the United States increased by an estimated 6 quads (8 percent) between 1985 and 1988. This gain breaks a 13-year trend, begun in 1972, of relatively level energy use (15). The energy intensity of the economy continued to decline from 1985 to 1988, but by only –1.0 percent annually as opposed to –2.4 percent annually from 1972 to 1985.

Detailed data is lacking on how manufacturing fared during this 3-year period, but preliminary figures suggest a 6-percent increase in energy use.[4] There is, however, no indication that the energy efficiency of production processes declined. In fact, the annual rate of investment in new plants and equipment from 1985 to 1988 was 7 percent, as opposed to 5 percent from 1972 to 1985. It is likely that these new investments boosted energy efficiency (47).

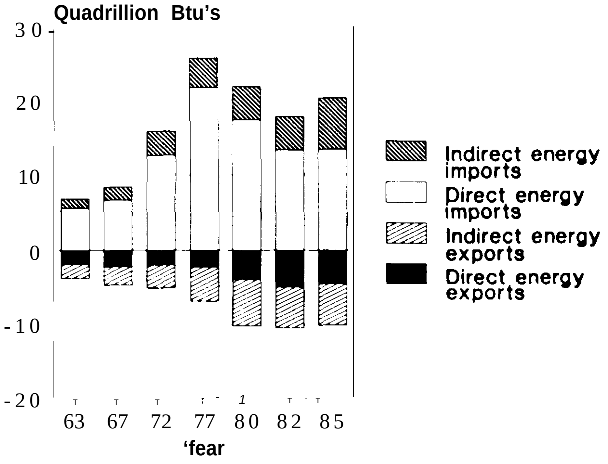
Rather, a reduction in the cost of energy, coupled with increased spending and changes in what was being bought, favored a shift towards relatively

[2] This estimate matches the U.S. Department of Energy's 1984 estimate (48) and is roughly in line with the 8 quads estimated for the energy embodied in 1984 exports in another recent U.S. Department of Energy study (54).

[3] This section is based on ref 44.

[4] Preliminary data from U.S. Department of Energy's *1988 Manufacturing Energy Consumption Survey*, supplied to OTA Apr. 5, 1990, by J L Preston.

Figure 6-4-Direct and Indirect Energy Use Associated With Imports and Exports*



The United States directly imports and exports energy. Although direct exports have stayed relatively steady, imports rose dramatically between 1963 and 1977 and then declined from 1977 to 1985. The United States also uses energy indirectly in the form of energy embodied in nonenergy exports (e.g., grain) and imports (e.g., autos). Prior to the emergence of a trade deficit this indirect use of energy was in balance, but by 1985 the indirect use of energy associated with imports boosted our dependence on foreign sources of energy by 50 percent.

• Production recipe kept constant at 1985 level.

SOURCE: 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).

energy-intensive industries from 1985 to 1988[5] (44), which could account for the increased energy consumption by manufacturing. For example, nondefense purchases by the Federal Government fell in real terms by 16 percent over the 3-year period, and defense purchases, which are about one-and-a-half times as energy intensive, grew by 10 percent (47). The export sector also grew faster than other economic sectors over this period, increasing its real share of GNP from 10 to 13 percent. Since most exports are manufactured goods, such a shift tends to result in increased energy use. Contributing to the export surge were such energy-intensive products as aluminum (44-percent growth in exports) and steel mill products (121-percent growth in exports) (l).

The shift toward more energy-intensive industries might be a temporary one. Two potentially conflicting policy goals may interact to shape future manufacturing-the desire, on the one hand, to improve the sector and revive exports to lessen the trade deficit (44); and the need, on the other hand, to reduce CO_2 emissions by shifting from more to less energy-intensive manufacturing activities.

ANATOMY OF ENERGY USE IN MANUFACTURING

The previous section provided abroad perspective on manufacturing's energy use, which is useful for a general understanding of the sector and its relationship to the economy. This section tracks how energy is specifically used in manufacturing, particularly by the four most energy-consumptive manufacturing industries: primary metals, paper and allied products, chemical and allied products, and petroleum refining.

Services Provided bv Energy in the Manufacturing Sector

About half of the fossil fuels and electricity used by industry provides process heat, steam, and cogenerated heat and steam (see figure 6-5). Energy in manufacturing is also used for feedstocks, mechanical drive, electrolysis, lighting, and space heat.

Boilers and Process Heaters

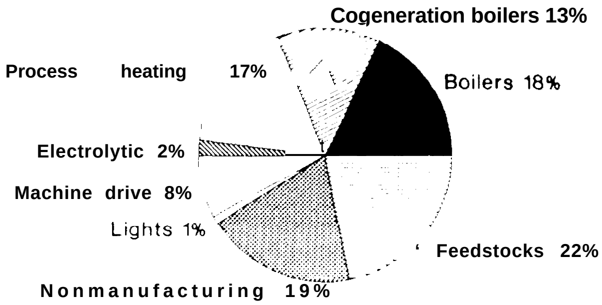
The basic materials industries (metals, chemicals, petroleum) rely on many high-temperature processes, hence large amounts of process heat. For example, steel is heated so that it can be shaped into specigic products such as sheet, tube, or wire. Process heat also accounts for most of the energy used for metals smelting, petroleum refining, and cement manufacture. Improved insulation around heaters, computer-controlled regulation of fuel combustion, and increased utilization of waste heat have led to major improvements in process-heat fuel efficiency since 1973 (37).

Cogeneration of Electricity and Steam

Cogeneration refers to the combined production of heat (usually steam) and electricity from the same energy source. Nationwide about 20 to 25 percent of the cogenerated energy output is electricity, the remainder is steam (14). Depending on the degree to which cogenerated steam is utilized, cogeneration technologies can almost double fuel efficiency (33) for user firms, reducing their need to purchase energy. Cogeneration is usually restricted by economic considerations to applications where heat of

[5] Data for 1985 and 1988 from refs. 47 and 46, respectively.

Figure 6-5—1987 Industrial Energy Use by Function (percent)



SOURCE: Gas Research Institute, *Industrial Natural Gas Markets: Facts, Fallacies, and Forecasts* (Washington, DC: 1989).

low-to-moderate temperature is needed on a regular basis. In 1958, more than one-fifth of the electricity manufacturers used was cogenerated. This dropped to 8 percent in 1981, but rebounded to 10 percent in 1986 (33). This recovery trend is likely to continue; in fiscal year 1988, more than 300 cogeneration facilities with a planned capacity of 7,005 megawatts were registered for operations (12).

The four most energy-intensive manufacturing industries dominate use of cogeneration (see table 6-3). Industrial and commercial cogeneration capacity is currently about 23,000 megawatts, almost 4 percent of total U.S. electric generation capacity (19). An additional 60,000 megawatts may be technically and economically feasible (18).

Feedstocks

Unlike other energy services, feedstocks (i.e., petroleum feedstocks in chemicals and plastics manufacture) are raw material inputs to manufactured goods. Since feedstocks are generally not combusted (the notable exception is coke, used in steel manufacture), their consumption does not lead to emissions of greenhouse gases, except to the extent that heat is required to process them.

Mechanical Drive

Energy is used for mechanical drive equipment, conveyers, stamping presses, pumps, compressors, blowers, and fans (31). Diesel- and gasoline-driven engines provide a small amount of this energy service, but electric motors are by far the most prevalent machine-drive technology in manufacturing, accounting for two-thirds of industry's electricity use (9).

Table 6-3-Electricity Cogeneration by Industry, 1985

Industry	Million kWh	Percent
Paper and allied products	32,866	47
Chemicals and allied products	19,827	28
Petroleum and coal products	5,507	8
Primary metal industries	4,556	7
Food and kindred products	3,618	5
Transportation equipment	318	<0.5
Textile mill products	305	<0.5
Stone, clay, and glass products	207	<0.5
Machinery, except electrical	194	<0.5
Rubber and miscellaneous plastics	69	<0.5
Fabricated metal products	65	<0.5
Printing and publishing	26	<0.5
Other manufacturing	2,197	3
Total	69,755	100

NOTE: Total does not add to 100 due to rounding.

SOURCE: U.S. Department of Energy, Energy Information Administration, *Manufacturing Energy Consumption Survey: Consumption of Energy, 1985*, DOE/EIA-0512(85) (Washington, DC: November 1988), table 9, p. 39.

Electrolysis

Electrolytic processes use electricity, rather than heat and pressure, to change matter at the atomic level. Electrolytic processes account for 10 to 15 percent of all electricity used by manufacturing (9). Two industries, aluminum and chlorine manufacturing, dominate energy use for electrolysis (37). Gains in electrolysis efficiency can result in reductions of greenhouse gas emissions if the electricity is supplied by fossil fuels. In 1989, 70 percent of utility-generated electricity came from fossil fuel combustion (55).

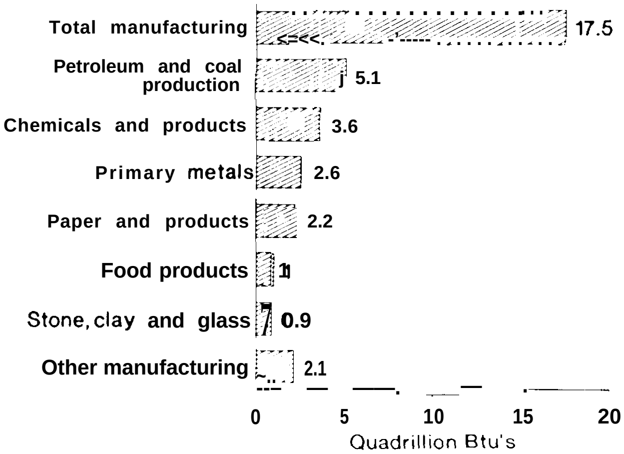
Space Heat

Manufacturing, by and large, uses the same space heating and cooling technologies as does the buildings sector (see ch. 4), although waste heat from thermal processes is employed in some cases. Potential gains in energy efficiency can be made by improving heating and cooling technologies, and by utilizing waste heat more extensively.

Nonmanufacturing Industry Uses

Nonmanufacturing energy use is concentrated in four industries: mining, natural gas production, agriculture, and construction. About one-quarter of nonmanufacturing industrial energy use is used to prepare natural gas for pipeline delivery; another one-quarter is used in off-highway vehicles in agriculture, mining, and construction. Most of the remainder is used in boilers and process heaters (14).

Figure 6-6-Consumption of Fossil Fuels and Electricity y by Selected Manufacturing Industries



SOURCE: U.S. Department of Energy, Energy Information Administration, *Manufacturing Energy Consumption Survey: Changes in Energy Efficiency 1980-1985,* DOE/EIA-0516*(85)* (Washington, DC: January 1990).

The Largest Users of Energy in the Manufacturing Sector

The four biggest manufacturing energy consumers are paper and allied products, chemicals and allied products, petroleum and coal, and primary metals (see figure 6-6). Collectively these industries account for over three-quarters of manufacturing's energy use. Each of the four industries is responsible for between 14 and 19 percent of manufacturing's CO_2 emissions, although their principal emission sources differ. The primary metals industry, for example, was third in terms of energy consumption but first in CO_2 emissions because of its heavy use of coal.

Each of these industries is an important "upstream' producer that sells its output to industries ''downstream' for further processing into final goods. Given this interdependence, efforts to curtail emissions should focus on the potential for improving energy efficiency, rather than on limiting output. Reducing domestic output would probably result in these materials being imported, which would do little to affect the global generation of greenhouse gases.

Paper and Allied Products

The paper industry consumes more fuel oil for heat and power than any other manufacturing industry (53). Nevertheless, both energy and cost reduction activities at the mills have reduced energy intensity (energy consumed per ton of product). Most important among the changes affecting energy use are:

1. water is being recirculated more, instead of being discharged, reducing steam requirements;
2. recycling of post-consumer fibers is increasing, which reduces pulping energy requirements;
3. thermo-mechanical pulping (TMP) (an improved method for grinding the wood) is increasing, boosting electricity requirements; and
4. cogeneration of electricity and steam, historically very strong at pulp and paper mills, continues to expand.

In addition, the use of biomass byproducts (pulping liquor, bark, sawdust) for energy has increased significantly. In 1972, 40 percent of the energy used by the industry was obtained from biomass; in 1985, 56 percent (33). As a result, the use of conventional fuels and electricity (including losses) for papermaking fell from 24.8 to 17.8 million Btu's per ton between 1972 and 1985, an average rate of decline of 2.5 percent per year.

Further gains in energy efficiency can be made in the paper industry by improved process optimization and pressing and drying, continued investment in cogeneration and other energy-efficient technologies, and increased paper recycling (41). Use of scrap paper, rather than virgin timber, permits the pulping process to be bypassed and reduces the

Photo credit: International Paper Co.

The settling pond in the foreground is part of the paper mill's environmental protection system. Behind looms the recovery boiler, which can meet a significant portion of a mill's energy needs by burning waste from the pulping process.

amount of energy required for manufacturing some grades of paper products (42).

Chemicals and Allied Products

In 1985, the chemicals industry was the second largest manufacturing industry in terms of energy use, consuming almost 3.6 quads of energy (53). It is the most complex of the four main energy-intensive industries. Instead of one specific product, it produces a wide range of intermediate and final goods, including agricultural chemicals, plastics, and paints. The purposes for which energy is used by the chemicals industry are correspondingly varied—the use of energy as feedstocks accounts for a large portion of consumption; large quantities of energy are also expended on process heat, steam heat, mechanical drive, and electrolysis. Natural gas is the dominant energy source in the industry, and is used both as a feedstock and as a source of heat and power.

From 1972 to 1985 the basic chemicals industry reduced its energy use per pound of product by 36 percent (32). This probably reflects the combined effects of initially high energy intensity, a high level of technical capability (e.g., the relatively large number of process engineers at chemical plants), and the modest thermodynamic requirement (e.g., low temperature) of many processes. A recent increase in cogeneration has provided a significant savings as well. The most substantial improvements in energy efficiency in the future will come as older equipment is replaced and as energy-inefficient processes are abandoned in favor of more efficient ones (33). The three main opportunities for increased energy efficiency through new technologies and/or process modifications are distillation, waste heat recovery, and product integration (i.e., whereby intermediate products such as ethylene are produced in petroleum refining complexes) (40).

Petroleum and Coal

The petroleum and coal industry is the largest energy user among manufacturing industries, consuming more than 5 quads of energy in 1985 (53). Petroleum refining dominates the industry's energy use, accounting for 90 to 98 percent of total annual energy consumption (37, 45, 49).

Unlike the paper industry, which has a large resource base of domestic timber and relies mainly on self-generated energy, U.S. petroleum refineries depend on a foreign supply of crude oil for both

Photo credit: PPG Industries, Inc.

A plant for the production of ethylene glycol is shown above. Glycol is used for making polyester fibers, photo film, and plastic bottles.

feedstock and energy source. This supply is subject to sudden changes in the price, quantity, and type of crude imported, all of which can influence energy consumption by refineries. Recent trends toward use of ''heavy' crude oil, for example, have increased the energy needed for processing as compared to lighter crudes.

Two additional factors influencing energy use are shifting demand for different types of products and environmental regulations. Demand has decreased for most sulfurous fuels (such as residual fuel oil) and high-octane unleaded gasoline (40). Environmental regulations limiting sulfur and lead content in fuels have mandated extra processing of fuel, hence increased use of energy for refining.

Improvements in refinery equipment and operations and computer process controls have led to nearly a 13-percent drop in the energy required per barrel of output from 1972 to 1985 (32). Key improvements have been made in steam systems. Large savings have resulted from rationalizing these systems, reducing leaks, renovating steam traps, using low-pressure steam that used to be vented, etc. In addition, new installations of boilers that cogenerate electricity and steam are allowing refineries to meet their medium pressure steam needs more efficiently.

Primary Metals

Steel and aluminum manufacturing account for most energy used in primary metals, which totaled about 2.6 quads in 1985 (53). The primary metals industry is the biggest industrial user of both coal and electricity, and is a leading emitter of CO_2, accounting for about 5 percent of total U.S. CO_2 emissions in 1985.

Steel—Production of steel involves many energy-intensive processes, most requiring large amounts of process heat to alter the chemical makeup of input materials and for shaping the steel into useful forms. Three types of steelmaking furnaces are currently used in the United States. Open hearth furnaces are the oldest and now least used type. Basic oxygen furnaces, which speed the steelmaking process by blowing oxygen into the furnace, are the most common type. Electric arc furnaces, which produce steel by electric arcing between carbon electrodes, are the most efficient type of furnace used today and are responsible for a growing share of U.S. steel production.

In the early and mid-1980s, U.S. producers reduced cost and improved energy efficiency by closing obsolete and unneeded mills and facilities—unfortunately, though, over half the jobs in the industry have been lost as a result. Between 1972 and 1985 additional investments in modernization reduced energy use per ton of steel mill products by 21 percent, or 1.8 percent per year (33). Specifically, the electric arc furnace has resulted in increased substitution of scrap for iron ore, which allows steelmakers to bypass the beneficiation and smelting processes and reduce energy use by 30 to 40 percent (37). Continuous casting, which permits increased working of hot steel, reduces the energy spent on reheating metal at various stages of the production process by about 15 to 20 percent, while vastly increasing the production yield (37). The continuous casting of steel has risen from 9.1 percent of all steel production in 1975 to 61.3 percent in 1988 (l).

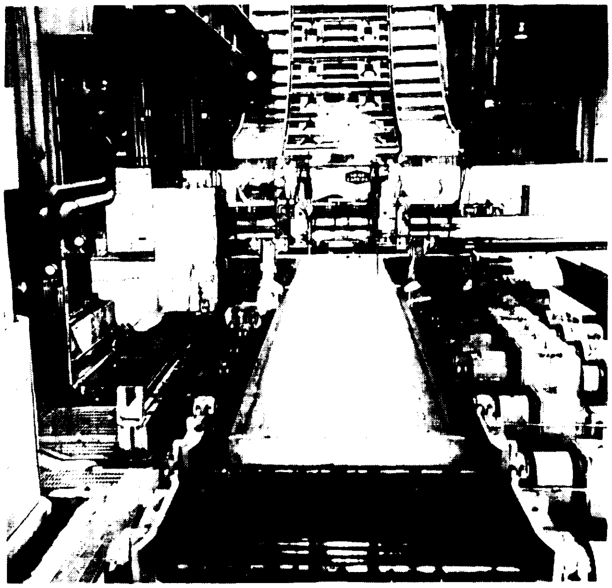


Photo credit: Amercan Iron and Steel Institute

The slab is being torch cut after emerging from the continuous slab caster. Continuous casting eliminates the need for ingot stripping, reheating, and primary rolling. Continuous casting is also more energy efficient because less metal must be returned to the steelmaking process in the form of waste.

Aluminum—The aluminum industry, like the steel industry, uses large quantities of energy to convert ore into metal and form the metal into finished goods. Manufacture of aluminum, however, involves somewhat different processes and a different mix of fuel types. Electricity accounts for most energy use in aluminum manufacture-77 percent in 1981 (45). Hydroelectric power, which currently provides about 10 percent of electricity generation capacity in the United States, accounts for over one-third of electricity used by the aluminum industry (10). Thus, electricity used in the aluminum industry is significantly less CO_2-intensive than the nationwide average. Production of aluminum has also become more energy-efficient in recent years due to the introduction of new technologies.

How quickly the energy efficiency of the primary metals industry improves in the future will largely depend on the rate of capital stock turnover. Because of slow growth in the primary metals industry and the long lifetimes of most capital equipment, accelerated replacement of energy-using equipment in the near future is unlikely without incentives.[6]

[6]An example of such an incentive is the Department of Energy's cooperative program with the steel companies to research new continuous steelmaking technologies.

There is potential for significant reductions in energy use in the near future through recycling of primary metals. Production of aluminum from scrap requires about 90 percent less energy than production from bauxite ore. Production of steel from scrap consumes about 40 to 50 percent less energy than production from iron ore (8). As of 1987, the United States recycled about 43 percent of all aluminum in municipal solid waste and over 55 percent of used aluminum beverage cans (42).

other Manufacturing Industries

Aside from the four largest industries, and the stone, clay, glass, and food processing industries, most manufacturing involves the intermediate processing of raw materials. The intermediate processing or ''second-tier' industries together accounted for 30 percent of the manufacturing sector's total use of fossil fuels in 1985, and almost half the sector's electricity use (49).[7] The heavy use of electricity reflects the extent to which these industries rely on mechanical drive. While second-tier industries do not require much process heat, they consume most of manufacturing's space heat energy, since they are generally more labor intensive than the basic materials industries. The stone, clay, glass and food processing industries also use significant natural gas for heating purposes.

In contrast to the four largest industries, second-tier manufacturers usually give low priority to improved energy efficiency and energy conservation. Hence, they offer a potentially significant target for reducing manufacturing's energy use (32).

Energy-Efficiency Improvement Techniques

Energy efficiency can be improved in manufacturing by changing operations and associated equipment to reduce energy use, and/or by significantly changing overall production processes (33). Equipment changes and energy conservation add-on technologies involve significant investment (typically $100,000 to a few tens of million dollars), which are often justified by reduced energy costs. Changes in the major production processes often require a new facility, at costs which usually exceed $100 million.

Energy-Efficient Operations

Energy-efficient operations are achieved, in part, by good housekeeping practices by well-qualified staff with leadership and support from top management. General energy conservation practices include: inspections to encourage conservation activity; training programs for operations of energy-intensive equipment; scheduling of energy-intensive activities; better space heating/cooling controls; systematic maintenance programs; accounting procedures to charge energy costs to specific production departments; and low-level investments such as for inspection equipment. At some plants, employee suggestions for and participation in energy conservation have led to improved operations (32).

Energy Management Systems

Equipment can be turned off or down as appropriate by an energy management system, i.e., a microprocessor connected to major energy distribution lines and/or equipment, which records and partly controls energy use. For example, it is still common industrial practice to leave electrical equipment on between production shifts. Large energy savings can be achieved by turning off equipment at these times and by selectively turning off or down equipment when production is below capacity. However, costly installation of wiring and switching is often required for systematic shut-downs of process equipment, lights, and fans.

Extensive changes may be required to selectively turn off appropriate equipment in a major factory. The typical cost of an energy management system in an auto plant with a load of 100 million kWh per year is about $750,000, with energy savings of about 10 percent. Exact costs and savings are, of course, site specific (33). Energy management systems have not yet been installed in most factories.

Changes in Energy-Intensive Equipment

Some of the major technologies that can reduce the energy intensity of a given process are more efficient burners, more efficient motors and lights, heat recovery, automatic controls, the capture and reuse of waste materials, cogeneration, and insulation. The following discussion expands on a few of these.

[7] These numbers include the stone, clay, glass, and food processing industries. Without these four industries, the manufacturing sector's use of fossil fuel and electricity would be 12 and 34 percent, respectively.

Heat recovery refers to the capture of waste heat, its application, and, in some cases, the upgrading of heat quality (i.e., with a heat pump). The main sources of heat are burner stack gases, heated product, and other hot material streams. The main applications are production of steam for general use (e.g., in waste-heat boilers) and the preheating of materials, such as water destined for a boiler, a product stream destined for a heater, or fuel or air destined for combustion.

High-efficiency motors are now routinely ordered at many firms when a motor is being replaced. (Most larger motors, however, are not replaced when they malfunction but are rewound.) High-efficiency motors typically cost about 20 percent more than standard motors (e.g., $60/hp compared with $50/hp) and save about 5 percent in electricity, depending on the size of the motor (2).

Motors can also be equipped with electronic variable-speed drives, allowing the motor to be run at a speed appropriate for the task at hand. Variable-speed drives typically replace conventional, constant-speed applications where:

1. motors provide more flow than is usually required,
2. motors work against variable-flow restriction devices, or
3. motors are turned on and off to regulate flow.

Typically, variable-speed drives reduce electricity use by about 20 percent (21).

Savings from more efficient lighting can be relatively large. If high-pressure sodium lamps replace mercury-vapor lamps for area lighting, energy savings of 50 to 60 percent can be achieved. Similarly, efficient high-frequency ballasts and specular reflectors can be installed in fluorescent lighting systems with electricity savings of 50 to 60 percent. With half as many bulbs this combination delivers about 90 percent as much light as the standard installation, Nonetheless, many improvements in lighting technology have yet to be widely adopted.

The importance of automatic controls is, of course, increasing as microelectronic technology improves. Such controls include:

1. process controls that sense characteristics such as temperature, chemical composition, and flow rate and immediately optimize them;
2. burner controls such as those that control the air-to-fuel ratio;
3. motor controls that, for example, adapt motor speed to the load; and
4. energy management control systems (discussed above).

While industry has made a start in applying some automatic controls (i.e., first generation burner controls and process controls), opportunities remain for further applications, particularly of more advanced models. Motor controls have not yet been extensively applied.

Changes in the Production Process

For this report, production activity is discussed at the level of an integrated mill or factory. The introduction of new processes in factories (i.e., new ways of transforming materials) and shifts in the relative use of competing processes are among the most important sources of declining energy intensity in materials manufacturing. The growing use of recycled material, both fabricators' scrap and post-consumer scrap, also has a major impact on energy savings. Only about one-tenth as much energy is required to melt scrap aluminum as to reduce aluminum ore to make the same amount of molten metal.

Many energy-saving opportunities relate to the capture and use of materials that have previously been disposed of, such as (flared) organic byproduct gases, organics in waste streams (e.g., in exhaust gases at a paint dryer), water, or steam condensate. Reducing material flows can also save energy.

Material recovery projects have been widely implemented since the first oil shock both to achieve energy savings and to meet pollution standards. Increased heat recovery equipment was widely installed where higher fuel prices made it very profitable; thus less retrofit activity can be expected in this area, unless fuel prices rise again.

Energy Savings as a Byproduct of Adopting Other Technologies

Potentially, the greatest decrease in emissions will not be the result of direct efforts to reduce energy consumption but of indirectly pursuing other economic goals like improved product quality,

Box 6-A—Potential for Industrial Energy Efficiency in the U.S.S.R. and Eastern Europe

U.S.S.R.

The Soviet industrial base is similar to that of past decades in the United States and many other OECD countries, with a strong reliance on energy-intensive industries (e.g., primary metal, mineral, mining, and chemical works), along with the production of energy itself. These will continue to be needed in order to produce the housing, appliances, vehicles, and transportation infrastructure desired by Soviet citizens.

Industrial energy consumption currently represents more than 50 percent of total energy use in the U.S.S.R. Ferrous metallurgy, fuels and power, machine building, and chemicals, petrochemicals, and petroleum refining consume 70 percent of all industrial energy, or about 40 percent of total Soviet energy consumption (34). Improving end-use energy efficiency in these industries is possible, but it will require continued reforms in the Soviet economic system (see ch. 9).

One Soviet analyst (3) estimated that the industrial sector could reduce energy use by about 20 percent by using the most efficient, currently available technologies. This might require a substantial increase in Soviet foreign trade with OECD countries, though, because the majority of these technologies are presently used and produced only in those countries.

Eastern Europe

Industry is the largest energy-consuming sector in Eastern Europe, accounting for 59 percent on average of primary energy consumption in 1985 (26). Despite major growth in the residential and commercial sectors, industrial energy use is expected to continue to dominate the energy supply and demand picture in Eastern Europe well into the 21st century.

Kolar and Chandler (26) projected that policies encouraging energy efficiency might reduce energy demand in the overall Eastern European industrial sector by about 6 quads by 2025. This does not reflect the effects of potential economic reform on structural changes and overall energy intensity. Some people in Czechoslovakia, for example, have called for reducing the production of steel to one-half of its present level, and even more dramatic changes have been recommended for nonferrous metallurgy and chemicals production.

lower product costs, or pursuing specialized markets.[8] For example, the innovative float process of making glass was not adopted solely because of energy savings, but because of the production flexibility that the new system offered (22). The major impact of the continuous casting of steel is not energy saved, but improved product yield (60). The shift in the steel industry from large, very energy-intensive open hearth furnaces to more energy-efficient basic oxygen and electric furnaces has occur-red in a large part because of the demand for small, regular shipments of products with special metallurgical and dimensional characteristics (17, 36). Metal stamping plants have implemented new techniques for cushioning their presses not because of the 10 percent energy savings involved, but because of the desire for a more consistent product achieved with fewer maintenance costs (33).

Canada's National Energy Board concluded that most of the industrial energy-efficiency gains that the country achieved have ". . . resulted from the adoption of new processes, motivated by concerns for competitiveness and productivity, rather than energy costs' (28). Future industrial savings are also likely to be associated dividends of larger goals, given the increased competition from foreign fins, the advent of information technologies that allow production to be more closely monitored, and the movement towards high-value-added products.[9]

In the U.S.S.R. and Eastern Europe, the industrial sector consumes a much larger share of total energy than in the United States. Many opportunities exist for energy savings in the rapidly changing industrial economies of these nations (see box 6-A).

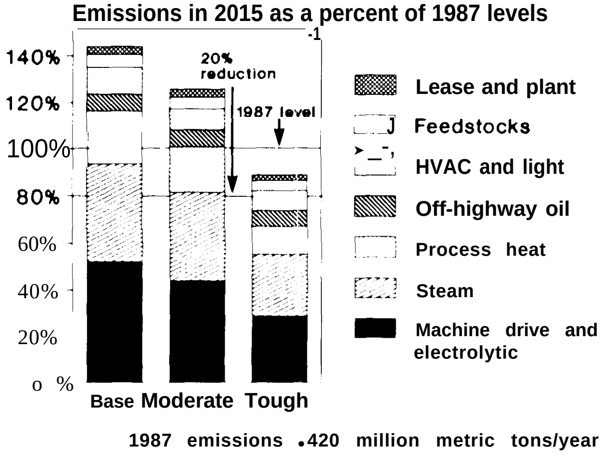
OTA EMISSION REDUCTION SCENARIOS

OTA developed an energy technology model to track the effects of various technical options to reduce CO_2 emissions (see app. A). Figure 6-7 summarizes CO_2 emissions from the manufacturing

[8] The steel industry is one example (17, 36).

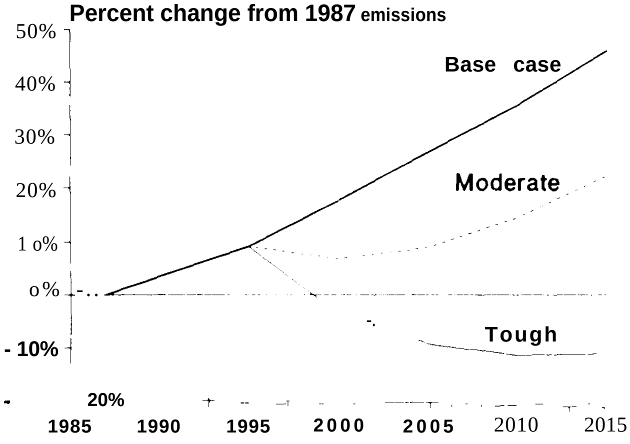
[9] For more on this conclusion, see refs. 27, 33.

Figure 6-7—Emissions in 2015 Under the Base Case, Moderate, and Tough Scenarios, by Energy Service Category



NOTE: The data presented above should be interpreted as the emissions reductions achievable in 2015 expressed as a percentage of 1987 emissions from industry, not as a percentage decrease in emissions *below* 1987 levels.
SOURCE: Office of Technology Assessment, 1991.

Figure 6-8—Summary of CO_2 Emissions Under the Base Case, Moderate, and Tough Scenarios, by Year

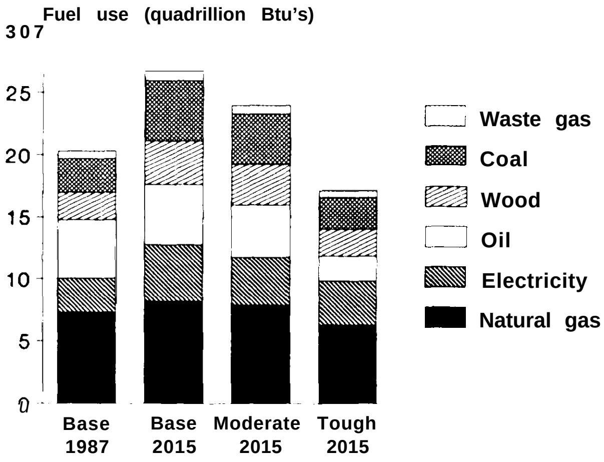


NOTE: The data presented above shows emissions reductions achievable in some future year expressed as a percentage decrease in emissions *below* 1987 levels.
SOURCE: Office of Technology Assessment, 1991.

sector in 2015 as a percentage of 1987 levels, by type of energy service, for the Base, Moderate, and Tough scenarios. Figure 6-8 shows our projections of industrial emissions as a percentage change from 1987 industrial emissions under the Base, Moderate, and Tough scenarios up to the year 2015. In the Base case or ‘‘business-as-usual scenario, no new policies are adopted, resulting in about a 45 percent emissions increase, from about 420 million metric tons of carbon in 1987 to about 610 million metric tons in 2015. Over the same period, energy use is projected to increase by about one-third. Carbon emissions increase more rapidly because coal and purchased electricity both gain market share over the period (see figure 6-9).

Application of technologies that are currently available and cost-effective on a life-cycle basis (the Moderate scenario) still result in emission levels in 2015 that are about one-quarter above 1987 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, do emission levels drop below the 1987 level by 2015, to about 10 percent below 1987 levels.

Figure 6-9—Fuel Use Under the Base Case, Moderate, and Tough Scenarios, by Fuel Type



SOURCE: Office of Technology Assessment, 1991.

Table 6-4 lists the technical options considered in each of the above categories. The column headings (Base case, Moderate, and Tough) denote the three different levels of commitment. Listed underneath them are technological improvements and operational changes that could be expected to occur as a result of the implementation of the strategy.

Table 6-4—industrial Sector Conservation Measures

	Base case	Moderate controls	Tough controls
1. *Operation and maintenance/existing stock:*			
Housekeeping	—	50/. savings by 2000	50% savings by 2000
Lighting retrofits	—	High-efficiency bulbs net 12% savings	High-efficiency bulbs net 12% savings
2. New *investments:*			
Motors	Standard motors	High-efficiency motors and ASD save 1070	High-efficiency motors and ASD save 30%
Lighting	Standard lighting	High-efficiency ballasts, reflectors net 50°/0 savings	Same as moderate controls
Product/process changes		Four major industries' energy intensity reductions average about 1.5°/0 per year[a]	Four major industries' energy intensities set to historical improvements,[b] other industries at -0.5%/yr, beyond Base case
Fuel switching	Coal gaining share, gas maintaining share	Same as Base case	No new coal boilers, market share goes to natural gas
Cogeneration	26 GW in 2005, 39 GW in 2015	700/0 of new and replacement boilers cogenerate steam and electricity	90°/0 of new and replacement boilers cogenerate steam and electricity y
3 *Accelerated turnover and new investments (technologies and rate):*			
Early equipment retirement	Not applicable	Not applicable	Average equipment lifetimes 5 years shorter
High efficiency (ISTIG) cogeneration	Not applicable	Not applicable	Replace 25% of new gas-fired cogeneration in 2000 and 50% after 2005 with ISTIG

[a]The following efficiency improvements were assumed for the Moderate Scenario: paper, 1.70/. per year; chemicals, 1.2"/. per year; petroleum, 1.3% per year; primary metals, 1 .8% per year.
[b]The following efficiency improvements were assumed for the Tough scenario: paper, 2.8?/. per year;chemicals, 3.8% per year; petroleum, 4.30/. per year; primary metals, 2,30/' per year.

ABBREVIATIONS: ASD = alternating speed drive; GW - gigawatts; ISTIG - intercooled steam-injected gas turbines.

SOURCE: Office of Technology Assessment, 1991.

While the column headings characterize levels of commitment measured in terms of overall costs, the row headings (Operation & Maintenance/Existing Stock, New Investments, Accelerated Turnover and New Technology) loosely reflect the lead times (going from short to long) associated with a particular group of changes. Operation & Maintenance/ Existing Stock focuses on improving efficiency within the confines of the existing capital equipment stock. New Investment includes what might occur if policies were adopted that steer purchasing decisions towards high-efficiency equipment. Accelerated Turnover and New Technologies simulate what might be possible with policies that hasten the development of new technologies and the retirement of old equipment.

The energy conservation opportunities in the industrial sector are more difficult to analyze than in other sectors because the uses of energy are very heterogeneous and are often interrelated. Energy conservation can result from investment in individual pieces of equipment (e.g., a high-efficiency motor) or in changes to a whole manufacturing process (e.g., continuous casting steel). To deal with this problem, the analysis of the industrial sector examines efficiency in specific types of equipment that are used in many types of industrial processes and specifically focuses on likely process changes in the four biggest energy-consuming industries—paper and allied products, chemicals, petroleum refining, and primary metals.

Note that in this analysis, emissions reductions are not linked to major changes in the utility fuel mix that produces electricity for industry. Because over half of U.S. electricity is produced by burning coal (the most CO_2-intensive fuel), the emissions reductions described in this chapter could be augmented by changing how electricity is made (see ch. 3).

Base Case

OTA's Base case projection of a 45 percent increase in emissions from 1987 to 2015 reflects the Gas Research Institute's 1988 baseline projections. Industrial production is projected to increase 2.7 percent per year, but energy use is estimated to grow more slowly. The result will be a continuing decline in the energy intensity of U.S. industry, including that of each of the four biggest energy using industries.

By 2015, we assume there will be about 39 gigawatts of industrial cogeneration capacity in the Base case. Most of the electricity is used internally by industrial fins, but about one-quarter is sold to utilities. Gas is projected to be the fuel most used for cogeneration, but coal's share increases significantly by 2015.

Moderate Controls

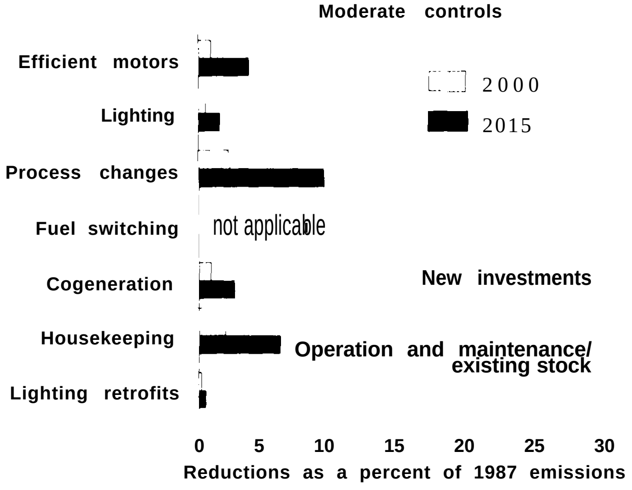
Adopting Moderate control measures could reduce CO_2 emissions by 77 million metric tons per year below Base case projections for 2015; emission levels would still exceed 1987 levels by 25 percent (see figure 6-7). Figure 6-10 shows the emissions reductions achievable in 2000 and 2015 by each of our Moderate control measures. Product and process changes that reduce the energy intensity of the four biggest energy-using industries achieve the greatest emissions reductions (about 9 percent of 1987 levels) (52), The impacts of other conservation measures (motors and lighting) may overlap with those of process and product changes; the scenario is adjusted to avoid double counting of the same emission reduction opportunities. Improvements in housekeeping and new, more efficient motors reduce emissions by 6 percent and 4 percent of 1987, respectively, by 2015.

Increased cogeneration based on gas and biomass achieves CO_2 emission reductions equivalent to about 3 percent of 1987 levels by 2015, even though energy delivered and consumed increases. The OTA model assumes that cogeneration systems are designed to deliver both electricity and steam for internal use rather than to maximize electricity production. The assumed design maximizes the technical fuel efficiency and therefore minimizes carbon emissions, even though in some cases it may not be the least-cost alternative.

Tough Controls

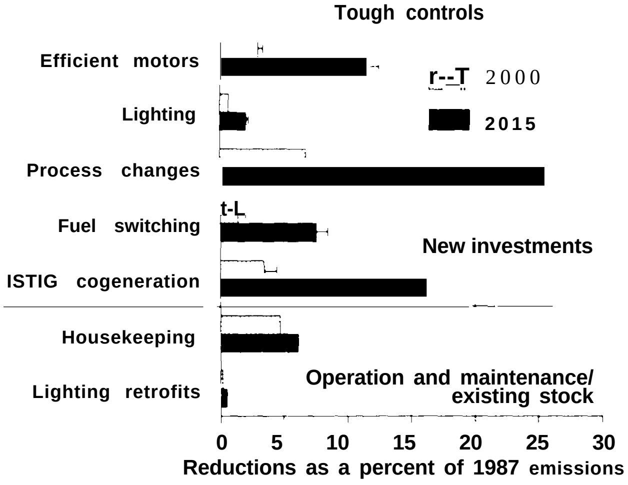
By 2015, emissions under the Tough control scenario fall to about 10 percent below 1987 levels (see figure 6-7). Total emissions are about 40 percent lower than the Base case in 2015. Figure 6-11 shows the emissions reductions in 2000 and 2015 for each of the Tough measures as percentages

Figure 6-10--CO_2 Emissions Reductions in 2000 and 2015 Expressed as a Percentage of 1987 Manufacturing Sector Emissions, by Control Method, Under the Moderate Scenario



NOTE: The data presented above should be interpreted as the emissions reductions achievable in a future year expressed as a percentage *of* 1987 emissions from industry, not as a percentage decrease in emissions *below* 1987 levels.
SOURCE: Office of Technology Assessment, 1991.

Figure 6-11—CO_2 Emissions Reductions in 2000 and 2015 Expressed as a Percentage of 1987 Manufacturing Sector Emissions, by Control Method, Under the Tough Scenario



NOTE: The data presented above should be interpreted as the emissions reductions achievable in 2015 expressed as a percentage *of* 1987 emissions from industry, not as a percentage decrease in emissions *below* 1987 levels. The thin horizontal bars show the additional reductions possible if existing equipment is replaced sooner than scheduled.
SOURCE: Office of Technology Assessment, 1991.

of 1987 levels.[10] Reductions from all Tough measures total about 210 million metric tons, roughly half of 1987 emissions. To achieve such reductions, equipment stocks (e.g., boilers, motors, etc.) must be replaced 5 years sooner than they normally would be. Operation and Maintenance/Existing Stock measures are the same as in the Moderate scenario, but are introduced more quickly.

Process changes occurring in all industries achieve about a 26 percent reduction by 2015, compared to 1987 emission levels, assuming the energy intensity of the four largest industrial energy users continues to decline at the 1980-85 rate. Other industries are assumed to experience an additional energy intensity reduction of 0.5 percent per year compared to the Base case.

High-efficiency motors, which use 30 percent less energy than standard motors, reduce emissions by 12 percent of 1987 levels by 2015. If existing motors are replaced 5 years sooner than scheduled, an additional 1 percent reduction can be achieved.

If the building of new coal-fired boilers is stopped, and the entire market share for new coal shifts to natural gas (the fuel-switching measure), an 8-percent reduction in industrial CO_2 emissions would be achieved by 2015 (9 percent if existing boilers are replaced 5 years sooner than scheduled).

New investments in cogeneration can achieve about a 7 percent reduction in CO_2 emissions by 2015, assuming that cogeneration provides 61 gigawatts (GW) in 2015 and meets 90 percent of new industrial steam demand.[11] New, more efficient cogeneration technologies, such as intercooled steam-injected gas turbines (ISTIG), should become widely available in the 1990s. We estimate that if ISTIG cogeneration replaces about half of the new gas-freed cogeneration after 2005, then industrial CO_2 emissions can be reduced by about 16 percent in 2015, relative to 1987 levels.

Because many of the Tough measures have overlapping effects, total reductions under the Tough scenario are lower than the sum of the reductions from each individual measure shown in figures 6-10

[10] This format should not be confused with the one presented in figure 6-8, which shows emissions as a percent change from 1987 levels

[11] Note that this category is not included in figure 6-11. The more stringent ISTIG cogeneration technology is presented instead.

and 6-11. For example, the potential reductions from cogeneration are lower if other conservation measures that lower the demand for steam energy are also assumed. On the other hand, other emissions reduction options may exist that were not included in this analysis. The potential savings calculated here should not, therefore, be taken as an absolute limit. In general, however, large emissions reductions may be very difficult to achieve by 2015, in part because of continued growth in the manufacturing sector, and in part because industry has already invested in energy efficiency.

Costs of the Tough Control Scenario

We estimate that the cost of all the Tough industrial control measures falls in the range of $18 billion to $55 billion per year. The cost of individual measures are summarized below and presented in greater detail in appendix A.

Use of more efficient motors and lighting and general housekeeping improvements are all measures that are either low cost or save money due to large fuel savings. We estimate cost savings from these measures of about $9 billion per year.

The extensive use of extremely efficient cogeneration technologies under our Tough scenario costs, on average, about an additional $0.02 to $0.07 per kWh of electricity generated. Costs for cogeneration total about $3 billion to $7 billion per year. The cost-effectiveness of these reductions is in the range of $55 to $120 per ton of carbon.

The moratorium on new coal industrial boilers (assuming natural gas is the fuel of choice) would increase natural gas use by about 2.3 quads over the Base case. At our 2015 prices, this costs about $14 billion per year, with a cost effectiveness of about $520 per ton of carbon reduced.

The largest share of the industrial reductions comes from process change;. We have no source of estimates for the cost of these reductions. We assumed a range of $120 per ton to $520 per ton (the upper bound of the cost-effectiveness of cogeneration to the cost-effectiveness of fuel switching from coal to natural gas). Total costs for process changes thus would fall in the range of about $10 billion to $43 billion,

POLICIES FOR REDUCING CO_2 EMISSIONS FROM THE INDUSTRIAL SECTOR

Strategies for reducing emissions of greenhouse gases from the manufacturing sector fall into three categories: those meant to reduce overall energy use, those intended to shift the composition of industrial output, and those meant to encourage switching from greenhouse gas-intensive energy sources to sources that emit fewer or no greenhouse gases. These strategies are outlined in greater detail below. Policy options are presented in a following section.

Policy Strategies

Changes in Energy Efficiency

The energy efficiency of a manufacturing process can be improved by increased housekeeping, equipment retrofit, or construction of entirely new production facilities. Housekeeping essentially involves increased labor and management inputs to reduce energy inputs. Equipment retrofit is a relatively inexpensive alternative to actual equipment replacement. However, equipment replacement or construction of entirely new facilities, though costly, offer the largest overall energy savings.

Improving energy efficiency in manufacturing can be quite cost-effective. Between 1976 and 1988, about 2,500 energy audits were performed free of charge for small and medium-sized manufacturers (i.e., under 180 employees) through the Energy and Diagnostic Center (EADC) program sponsored by the Department of Energy's Office of Industrial Programs. The program is administered by the University City Science Center in Philadelphia and currently has auditing centers at 18 universities, During 1987-88, the audits performed contained recommendations for savings of about 5 percent of the total energy use by these manufacturers, equivalent to a financial savings of $13.6 million. While these savings are certainly encouraging, much more potential for improvement exists: only half of the recommendations made by the energy auditors were implemented by the manufacturers.[12] Most (73 percent) of the energy savings resulted from improved conservation and efficiency in production and energy-service technologies (i.e., mechanical

[12]Research bearing on the impediments t. adoption of energy-efficient technology will be presented in a forthcoming OTA study, *U.S. Energy Efficiency. Past Trends and Future Opportunities.*

drive systems and boilers). The remainder was saved through housekeeping and in lighting and space conditioning systems.

Depending on assumptions made about investment interest rates, the manufacturers' annual rates of return from energy-conserving investments in 1987-88 were between 488 and 663 percent. The Federal Government, which paid for the audits, earned between 60 and 77 percent per year on its investment in increased taxes from manufacturers (25).

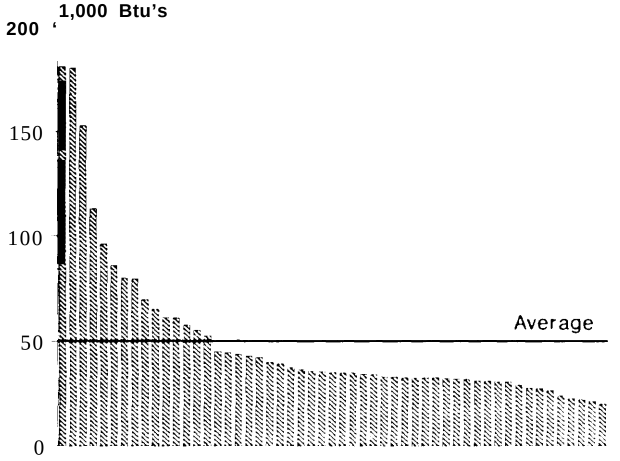
Changes in Output

The energy intensity of manufacturing industries is unevenly distributed (see figure 6-12). Of the 53 manufacturing industries, only 4 have a primary energy intensity of 100,000 Btu's or more per dollar output; 11 are between 50,000 and 99,999 Btu's; and 38 use less than 50,000 Btu's (roughly the average) per dollar of output (5). Thus, increased efficiency in a few industries or a realignment of the economy away from the most energy-intensive industries could have a significant effect on the overall energy intensity of manufacturing.

Indeed, decreased output of energy-intensive goods accounted for about one-third of the decline in energy use by the U.S. industrial sector between 1972 and 1982 (27). To the extent that consumers substitute less energy-intensive goods for more energy-intensive ones, CO_2 emissions from U.S. manufacturing can be reduced. However, the experience from 1985 to 1988 indicates that economic output can also swing in the opposite direction toward a more energy-intensive configuration. Moreover, imports of energy-intensive products increased in the period when U.S. manufacturing shifted from more to less energy-intensive goods. To calculate our total contribution to global problems like climate change, and to formulate effective energy reduction policies, it is important to include estimates of the energy associated with nonenergy imports. Failure to do so presents a false picture of U.S. energy use and of the potential for savings.

Advances in information technologies have made it possible to substitute information for materials, leading to changes in production that indirectly save energy. Instead of creating dozens of prototypes, for example, Levi Strauss Co. is using computers to test out new fabrics, patterns, and designs before ever cutting a piece of cloth (4). Thus, quality and

Figure 6-12—Ranking of Manufacturing Industries by Direct and Indirect Primary Energy Use



SOURCE: S. Casler and B. Hannon, "Readjustment Potentials in Industrial Energy Efficiency and Structure," *Journal of Environmental Economics and Management* 17:93-108, 1989.

flexibility are enhanced and the use of materials and associated energy is reduced. In essence, a shift in output has occurred, with the software and information technology industries gaining (43a).

Fuel Switching

Manufacturing industries can also reduce emissions of greenhouse gases by switching to 'cleaner' energy sources. Natural gas and oil emit less CO_2 per unit of energy than does coal, and no greenhouse gases are directly emitted by generation of electricity at hydroelectric or nuclear powerplants. In one analysis, researchers found large-scale movement towards refined petroleum products and electricity from 1967 to 1972 and a movement away from natural gas from 1972 to 1977, indicating that ". . . many industries are able to exercise a great deal of flexibility in their use of fuels over spans of time as short as five years' (5).

The decision to switch the type of energy used, however, may be influenced by technical, economic, environmental, and energy security factors. Any of these factors may constrain movement from one type of energy to another. Potential supply restraints also can limit opportunities for fuel switching. Nevertheless, energy switching could reduce CO_2 emissions from manufacturing by as much as 5 to 10 percent; these reductions could be much higher in the long run if reliable, nonfossil energy sources are developed, without seriously conflicting with manufacturing interests.

Policy Options

Several categories of policies can be used to implement the emission-reducing strategies outlined above. They include regulatory and financial policies; electric utility programs; and information and research and development policies. Unfortunately, no single policy is without flaws. Careful coordination of several types of policies is probably the best approach for achieving significant emission reductions from the manufacturing sector.

Opportunities for reducing CO_2 emissions in this sector are more difficult to identify than in other sectors because of the wide variety of uses for energy. Thus, those policies that affect energy consumption in general, for example, carbon taxes or marketable permits for carbon emissions, are a logical choice for this sector. Moreover, because industrial decisionmakers are often both more knowledgeable and sensitive to prices than, for example, residential energy consumers, one would expect market-oriented options to be relatively more effective. Nonetheless, other types of policy approaches in concert with market-oriented approaches can help to ensure success.

Without any intervention, emissions may increase by about 45 percent by the year 2015. Federal policies to encourage energy efficiency, fuel switching, and CO_2 offsets in the manufacturing sector have the potential to reduce the sector's CO_2 emissions to about 10 percent below current levels in the next 25 years. Such changes will not come about by themselves. A coordinated policy effort at the Federal level is needed to ensure success.

Regulatory Policies

One possible means of regulating CO_2 emissions from manufacturing is to require permits for CO_2 emissions. Manufacturers could be issued permits to cover a prescribed level of emissions, for example a set percentage of 1990 emissions. Reductions can be accomplished by implementing energy -efficient technologies or fuel switching, or by supporting approved reforestation/afforestation projects to offset CO_2 emissions from manufacturing activities (see ch. 7). It would be up to the manufacturer to choose the most cost-effective strategy, depending on costs of available resources. Firms could be allowed to trade their unused carbon permits to other firms whose emissions exceed permit levels, thereby creating a market for carbon emissions. Marketable permits are the basis of the U.S. regulatory approach for phasing out emissions of CFCs and for reducing sulfur dioxide emissions to control acid rain. Marketable carbon permits are likely to be more difficult to implement than permits for CFCs or sulfur dioxide; nevertheless, such a system may still be less intrusive to firms than mandated standards or equipment. Marketable permits are discussed in greater detail in chapter 3.

Another more traditional regulatory policy is to require efficiency standards for common energy-using equipment, similar to those existing for automobiles and some appliances. Motors are prime candidates for such standards. Efficiency standards historically have been opposed by industry because standards can be inflexible (33). However, decisions such as motor purchases and recycling are made by professionals dealing with a wide variety of specific situations and are not immune to shortsightedness or mistakes. Even so, the rationale for mandating the use of a particular type of equipment is not as strong as it is for setting efficiency standards for cars or appliances; the consuming public might not be competent or willing to evaluate the technical details bearing on efficiency.

Electric Utility Programs

Some programs sponsored by electric utilities—Demand Side Management (DSM)--offer another means of achieving reductions in greenhouse gas emissions from manufacturing. The cost to utilities of facilitating energy savings (especially in large energy users such as industry), may be competitive with the cost of adding new supply capacity: the utility interacts with the customer to conserve energy and maximize profits. Many of these programs are in their infancy and it is too early to judge their effectiveness. The major programs are:

1. rebates to customers who install agreed-on kinds of equipment;
2. payments (by the utility that solicits bids) for electricity savings resulting from installations;
3. low-interest loans to customers for conservation installations; and
4. installation, at utility cost, of conservation equipment (33).

See chapters 1 and 3 for more discussion of DSM.

Many large industrial customers of electric utilities receive special lower rates because they supply the utility with a large, dependable portion of electricity demand. Utility programs could be used to reduce greenhouse gas emissions by making these special rates contingent on improved use of electricity. This differs from least-cost planning in that the financial burden of improving energy use is placed on the manufacturer, not the utility.

Energy or Carbon Taxes

The price of energy is obviously a very important factor affecting its use. Prices can be affected through a carbon tax, energy taxes (e.g., an oil-import fee), or regulation of electricity prices, to name a few. These are discussed in greater detail in chapter 3.

A carbon tax is a particularly effective way of levying the heaviest economic sanctions against the worst emitters of CO_2. Under such an approach, the tax would be highest on coal, low for natural gas, and zero for noncarbon sources.

Using several econometric models, the Congressional Budget Office estimated that a carbon tax of $100 per ton would hold CO_2 emissions at from about current levels to as much as 25 percent below current levels by 2000 (38). Within the industrial sector, the tax is estimated to lower CO_2 emissions in 2000 by between 10 and 35 percent below Base case emissions in that year. The higher reduction estimate is a result of a 70-percent reduction in coal use.

However, analyses of pricing policies such as carbon taxes may tend to *overemphasize the* role of price. The fact that the energy intensity of the economy began to decline before the first oil shock and continued to fall during periods of declining energy prices suggests that decisions about energy use are not solely contingent on price. Energy prices are important in decisionmaking, but are not the only consideration. For example, reliability of supplies is extremely important; facilities have been added at many factories so that both natural gas and residual oil can be burned and electricity generated.

Other very important considerations in energy decisionmaking are the connections between energy-using technology and product quality, yield of materials, maintenance of equipment, capacity of production, and so forth. Energy conservation measures are not undertaken if managers believe that the measures are at all likely to interfere with production or if the return on investment is not extremely high. In most industries, energy costs are not that important in the overall scheme of production. However, many projects undertaken primarily to boost product quality or to further automate production have side benefits including saving energy. Such energy-conservation projects, once identified, can be readily undertaken.

Unlike other sectors, such as buildings or electricity generation, nearly every manufacturing industry faces increasingly intense foreign competition. Caution should be exercised in increasing costs to domestic manufacturers if there is not a commensurate increase in costs to foreign competitors, or some sort of equalizing export subsidy. Unless the costs of policies are relatively equal worldwide, domestic manufacturers could beat a unique disadvantage and demand would conceivably shift from domestic producers of a product to foreign firms, doing little to curb the global production of greenhouse gases.

Tax Incentives

Much of the energy-using equipment in industry is old and inefficient compared to the best available technology. In 1975, for example, more than 70 percent of equipment in manufacturing was at least 15 years old and more than half was over 25 years of age (40), Because in many cases replacing old equipment improves energy efficiency by 10 to 50 percent, financial policies (such as, tax credits or accelerated tax depreciation schedules aimed at stimulating rapid replacement of older equipment with more energy-efficient stock) have potential for achieving improvements in energy use. Newer equipment also generally improves the overall productivity and competitiveness of the company.

This strategy has been tried in the past. The National Energy Act (1978) provided a 10-percent added energy investment tax credit (EITC) for certain energy conservation investments (as well as tax credits for certain energy supply investments). The tax credits were available until 1985. They applied to a specific list of technologies such as heat recovery devices.

One study of the EITC concluded, based on interviews and scrutiny of records at 15 participating corporations, that the 10-percent EITC seldom affected investment decisionmaking even though the tax credit was almost always applied for (33). In effect, almost all of the identified investment projects relating to conservation provided excellent returns and probably would have been undertaken

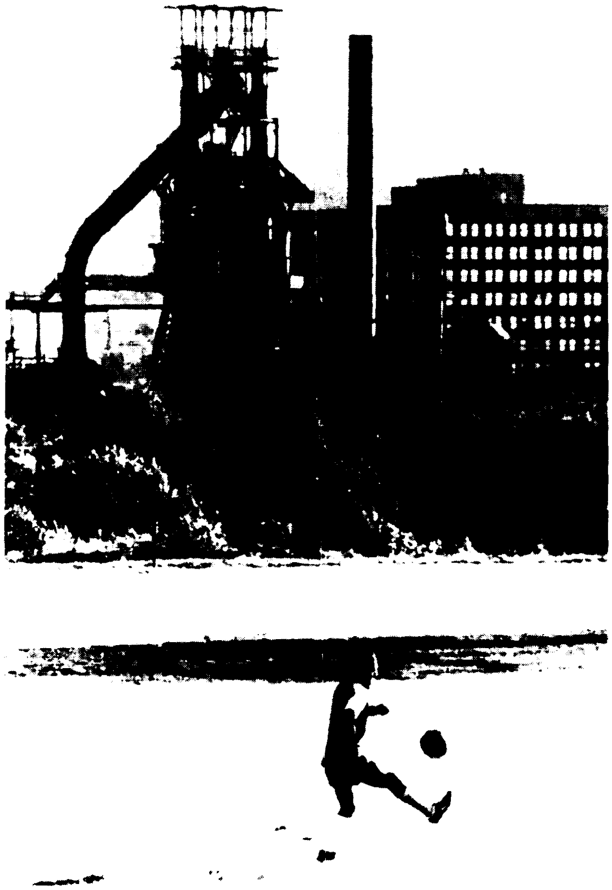


Photo credit: M. *Procter*

Bethlehem Steel main plant in Pennsylvania

even without the EITC. Many firms did not even factor the EITC into their financial evaluation. An additional objection to the EITC was that it specified technologies; it thus ran counter to the essence of technical change, which thrives on multiple new technologies and concepts and often involves multipurpose goals.

Informational Policies

A major barrier to reducing emissions from the manufacturing sector is a lack of information about how to improve energy use. Informational policies can include performance goals, the collection of performance data, energy performance labeling of equipment, training, or performance audits (32a). The Department of Energy's Office of Industrial Programs EADC program and its research and development information transfer program are examples of successful Federal policy in this area. Initiated in 1976, the EADC serves to transfer state-of-the-art research information and energy analysis expertise to manufacturers, who are able to use the information for practical purposes. With EADC finding, faculty and students at 18 universities perform free energy audits for small and medium-sized manufacturers in more than 30 States. From 1976 to 1988, nearly 2,500 audits were undertaken, proposing a total of about 82 trillion Btu's of energy savings, mainly from efficiency improvements associated with cogeneration, space heating, lighting, and process equipment maintenance and replacement (in descending order of cost savings). These recommendations represented about $400 million (nominal) in cost savings to industry. Actual implementation of EADC's recommendations yielded savings of 50 trillion Btu's of energy and $247 million (nominal) over the 12-year period. The program has had a cumulative cost to the Federal Government of $11.25 million through 1989 (25).

The success of programs such as EADC depends largely on the quality of work being performed; to expand the program would require a significant increase in the number of knowledgeable professionals involved. To the extent that increases are possible, the success of EADC seems to make an attempt worthwhile.

Research and Development

Research and development sponsored by OIP in waste energy reduction and industrial process efficiency is projected to save more than 3 quads of energy per year by the year 2000, based on continued funding of $30 million per year (1 1). Other federally sponsored research, such as that done at Oak Ridge National Laboratory (ORNL), will also contribute to improved energy technologies. Particularly promising research areas identified by ORNL are: improved use of catalysts in chemical production, intelligent sensors and controls, heat recovery and cogeneration, and separation techniques (29). Research and development in nonenergy areas, such as materials science, also holds promise for partial replacement of energy-intensive materials like steel and aluminum. Likewise, research and development into the quality of recycled goods could help reduce energy use by increasing demand for recycled materials such as paper, steel, and aluminum (32a).

CHAPTER 6 REFERENCES

1. American Iron and Steel Institute, *Annual Statistical Report, 1988* (Washington, DC: 19 W).
2. Baldwin, S.F., "The Materials Revolution and Energy-Efficient Electrical Drive Systems," ***Annual** Review **of** Energy* 13:67-94, 1988
3. Bashmakov, I. A., "Comparative Analysis of Energy Development in the USSR, USA, and Western Europe: 1970-2000," paper presented at the *International Energy Workshop* (Laxenburg, Austria: International Institute for Applied System Analysis, June 20-22, 1989).
4. Business Week, "Computer Graphics Are Animating Another Market," *Business Week*, p. 92, Mar. 16, 1987.
5. Casler, S. and B Hannon, "Retijustment Potentials in Industrial Energy Efficiency and Structure," *Journal of Environmental Economics and Management* 17:93-108, 1989.
6. Cleveland, C. J., R. Stanza, C.A.S. Hall, and R. Kaufman, "Energy and the U.S. Economy: A Biophysical Perspective," *Science* 225:890-897, Aug. 31, 1984.
7. Doblin, C. P., "Declinmg Energy Intensity in the U.S. Manufacturing Sector," ***The** Energy **Journal*** 9(2): ***109-135,*** 1988.
8. Ehrlich, A H., P R. Ehrlich, and J P. Holdren, *Ecoscience Population, Resources, Environment* (San Francisco, CA: W.H. Freeman & Co., 1977)
9. Electric Power Research Institute, *Efficient Electricity Use* ***Estimates*** *of Maximum Energy Savings* (Palo Alto, CA: March 1990)
10. Electric Power Research Institute, ***Prospects for U.S. Basic Industries, 1986*** *-2000. Implications for Electricity Demand* (Palo Alto, CA. March 1986).
11. Energetics, Inc., *Non-Energy **Impacts** of **industrial** Energy Conservation*, final task report, prepared for U S. Department of Energy (Columbia, MD: September 1985),
12. Flavin, C, R. Piltz, and C, Nichols, ***Sustainable** Energy* (Washington, DC: Renew America, 1989).
13. *Gas* Research Institute, *Baseline* **Projection Data** *Book,* 1988 *GRI Baseline Projection* **of U S.** *Energy* **Supply and Demand to** *2010* (Washington, DC: 1988).
14. Gas Research Institute, ***Industrial Natural*** Gas *Markets: Facts, Fallacies, and Forecasts* (Washington, DC: 1989).
15. Geller, H. S., "Testimony presented to the Subcommittee on Energy and Power, Committee on Energy and Commerce, U.S. House of Representatives, Feb. 7, 1989."
16. General Energy Associates, "Industrial Cogeneration Potential: Targeting of Opportunities at the Plant Site" (Washington, DC: U S. Department of Energy, 1982).
17. Gold, B., "Technological Change and Vertical Integration," *Managerial and Decision Economics,* vol. *7, 1986.*
18. Gross, T., Office of Industrial Programs, U.S. Department of Energy, personal communication, May 11, 1989.
19. Hagler, Bailly, Inc., *Cogeneration and Small Power Generation Data Base* (Washington, DC. RCG/Hagler, Bailly, Inc., December 1988).
20. Huntington, G.H. and J G. Myers, "Sectoral Shift and Industrial Energy Demand: What Have We Learned?" unpublished paper for ***Energy Modeling*** *Forum 8.3* (Palo Alto, CA: Stanford University, May 1986).
21. Kahane, A. and R. Squitieri, "Electricity Use in Manufacturing," *Annual Review of Energy* 12:223-252, *1987.*
22. Kelly, H.C et al., "Energy Use and Productivity: Current Trends and Policy Implications," *Annual* ***Review of*** Energy 14:321-352, 1989.
23. Kelly, W.J. et al., "Opportunities for Improvement in the Energy Efficiency of Soviet Blast Furnaces: A Demographic Approach," paper presented at 51st ***Annual Conference of the Southern Economic Association (New*** Orleans, LA: Nov. 6, 1981),
24. Kelly, W.J. and T.P. Spengler, "Application of Soviet Technology in Japanese Ferrous Metallurgy," paper presented at *20th National Convention of the Amen"can Association for the Advancement of Slavic Studies* (Honolulu, HI: November 1988).
25. Kirsch, F. W., *Energy Conserved and Costs Saved by Small and Medium-Sized Manufacturers: 1987-88 EADC Program Period* (Philadelphia, PA: University City Science Center, June 1990).
26. Kolar, S. and W.U. Chandler, "Energy and Energy Conservation in Eastern Europe, report prepared for U.S. Agency for International Development (Washington, DC: Battelle Memorial Institute, Pacific Northwest Laboratories, 1990).
27. Marlay, R.C., "Trends in Industrial Use of Energy," *Science* 226: 1277-1283, 1984.
28. National Energy Board, ***Canadian Energy:*** *Supply and* ***Demand, 1987-2005,*** Canada, September 1988
29. Oak Ridge National Laboratory, ***Energy*** *Technology R&D: What Could Make a Difference? (Oak* Ridge, TN: December 1988).
30. Roop, J. M., "Energy Implications of Structural Change in the United States Economy, paper presented at *IEA-Energy Demand Analysis Symposium* (Paris: Oct. 12-14, 1987).
31. Ross, M., "Energy Consumption by Industry," *Annual Review of Energy* 6:379-416, *1981.*
31a. Ross, M., "Industrial Energy Conservation," *Natural Resources Journal* 24(2):369, April 1984.
32. Ross, M., "Energy Use in Manufacturing," contractor report prepared for U.S. Congress, Office of Technology Assessment, October 1988.
32a. Ross, M., "The Potential for Reducing the Energy Intensity and Carbon Dioxide Emissions in U.S. Manufacturing" (Ann Arbor, MI: University of Michigan, unpublished paper, 1990).
33. Ross, M., "Improving the Energy Efficiency of Electricity Use in Manufacturing," Science 244:311-317, Apr. 21, 1989.
34. Sagers, M.J. and A. Tretyakova, *Fuel and Energy Use in the Soviet Metallurgy Industries*, Center for International Research, U.S. Bureau of the Census, CIR staff paper No. 28 (Washington, DC: July 1987).
35. Sagers, M.J. and A. Tretyakova, *USSR: Energy Consumption* ***in the Chemical, Petrochemical, and Petroleum Refining Industries,*** Center for International Research, U.S. Bureau of the Census, CIR staff paper No. 29 (Washington, DC: September 1987).
36. Szekely, J., "Can Advanced Technology Save the U.S. *Steel* Industry?" Scientific American 237(1):40, 1987,
37. Thoreson, R. et al., "Industrial Fuel Use: Structure and Trends," *Annual Review of Energy* 10: 165-200, 1985.
38. U.S. Congress, Congressional Budget Office, ***Carbon** Charges **as a Response to** Global **Warming:** The Effects of Taxing* Fossil *Fuels* (Washington, DC: U.S. Government Printing Office, August 1990).
39. U.S. Congress, Office of Technology Assessment, ***Industrial*** and Commercial *Cogeneration*, OTA-E-192 (Springfield, VA: National Technical Information Service, 1983).
40. U.S. Congress, Office of Technology Assessment, *Industrial Energy Use, OTA-E-198* (Springfield, VA: National Technical Information Service, June 1983).
41. U.S. Congress, Office of Technology Assessment, *Wood Use: U.S. Competitiveness and Technology, OTE-E-21O* (Springfield, VA: National Technical Information Service, August 1983).
42. U.S. Congress, Office of Technology Assessment, *Facing America's Trash: What Next for Municipal Solid* Waste?, OTA-O-424 (Washington, DC: U.S. Government Printing Office, October 1989).
43. U.S. Congress, Office of Technology Assessment, *Making Things Better: Competing in Manufacturing,* OTA-ITE-443 (Washington, DC: U.S. Government Printing Office, March 1990).
43a. U.S. Congress, Office of Technology Assessment, *The U.S. Textile and Apparel* ***Industry: A** Revolution **in Progress, OTA-TET-332*** (Washington, DC: U.S. Government Printing Office, April 1987).

44. 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).
45. U.S. Department of Commerce, Bureau of the Census, *Census of Manufactures: Fuels and Electric Energy Consumed* (Washington, DC: *1972,* 1977, 1981, 1982).
46. U.S. Department of Commerce, Bureau of Economic Analysis, Survey *of Current Business 69(9)* :s1-s2, *1988.*
47. U.S. Department of Commerce, Bureau of Census, *Statistical Abstract of the United States, 1989* (Washington, DC: 1989).
48. U.S. Department of Energy, Office of Policy Planning and Analysis, *Energy Use Trends in the United States 1972-1984* (Washington, DC: May 1985).
49. U.S. Department of Energy, Energy Information Administration *Manufacturing Energy Consumption Survey: Consumption of Energy, 1985,* DOE/EIA-0512(85) *(Washington DC: 1985).*
50. U.S. Department of Energy, Energy Information Administration *Monthly Energy Review* (Washington DC: January 1987).
51. U.S. Department of Energy, Energy Information Administration *Annual Review of Energy, 1987, 1988,* DOE/EIA-0384(87) (Washington, DC: May 1988).
51a. U.S. Department of Energy, Energy Information Administration *Annual Review of Energy, 1989,* DOE/EIA-0384(89) (Washington, DC: May 1989).
52. U.S. Department of Energy, Energy Information Administration *Monthly Energy Review* (Washington, *DC:* June 1988).
53. U.S. Department of Energy, *Energy Conservation Multi-Year Plan: 1990-1994* (Washington, DC: August 1988).
54. U.S. Department of Energy, Office of Policy Planning and Analysis, *Energy's Role in International Trade: Structural Change and Competitiveness* (Washington, DC: July 1989).
55. U.S. Department of Energy, Energy Information Administration *Manufacturing Energy Consumption Survey: Changes in Energy Efficiency 1980-1985,* DOE/EIA-0516(85) (Washington DC: January 1990).
56. U.S. Department of Energy, Energy Information Administration *Annual Review of Energy, 1990,* DOE/EIA-0384(89) (Washington DC: May 1990).
57. U.S. Department of the Interior, Minerals *Yearbook 1985* (Washington, DC: U.S. Government Printing Office, 1986).
58. U.S. Federal Reserve Bank, *Federal Reserve Bulletin* (Washington, DC: Board of Governors of the Federal Reserve System, November 1989).
59. walker, w., ''Information Technology and The Use of Energy,'' *Energy Supply,* pp. 460461, October 1985.
60. Young, E., American Iron and Steel Institute, remarks at OTA Energy Use in Industry Workshop, Washington, DC, May 11, 1989.