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Manufacturing Consumption of Energy 1991

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Executive Summary

The *Manufacturing Consumption of Energy 1991* report presents statistics about the energy consumption of the manufacturing sector, based on the 1991 Manufacturing Energy Consumption Survey (MECS). The MECS is the only comprehensive source of national-level data on U.S. manufacturing energy use. The 1991 MECS is the third in an ongoing series of surveys conducted at 3-year intervals beginning in 1985. Pursuant to a provision of the Energy Policy Act of 1992, the MECS will be conducted biennially beginning in 1994.

The MECS surveys a nationally representative sample of manufacturing establishments by means of mailed questionnaires. The 1991 sample represented 98 percent of the U.S. manufacturing sector universe, which consists of all manufacturing establishments in the 50 States and the District of Columbia. Compared with the 1988 MECS, the designed sample size for 1991 was increased from 12,065 manufacturing establishments to 16,054 establishments.

The following are some of the key findings of the survey:

- The Primary Consumption of Energy for All Purposes in the manufacturing sector was 20.3 quadrillion Btu of energy in 1991, compared with 20.1 quadrillion Btu in 1988. About two-thirds of this amount was used to produce heat and power and to generate electricity, with about one-third being consumed as raw material input.

- The most common energy sources—natural gas, net electricity, coal, liquefied petroleum gas (LPG), residual and distillate fuel oil, and coke—made up 64 percent of Primary Consumption.

- The amount of Total Inputs of Energy for Heat, Power, and Electricity Generation was 15.0 quadrillion Btu, compared with 15.5 quadrillion Btu in 1988.

- The byproduct fuels—blast furnace gas, waste gas, petroleum coke, pulping liquor, wood byproducts, and waste oils/materials—made up 28 percent of Total Inputs.

- End-use allocation was collected for about 65 percent of Total Inputs (9.7 quadrillion Btu). This consumption was allocated to three groups of end uses: indirect uses, mainly boiler fuel (3.3 quadrillion Btu); direct process uses, including use in motors, ovens, strip heaters, and kilns (5.0 quadrillion Btu); and direct non-process uses, including facility space-conditioning, facility lighting, other facility support, onsite transportation, electricity generation, and other miscellaneous uses (1.2 quadrillion Btu). Manufacturers consumed an additional 5.3 quadrillion Btu of energy for which end uses were not assigned. (The 1991 MECS collected data on end-use allocation for the first time.)

- Manufacturers had the capability to switch 2.8 quadrillion Btu of all the electricity, natural gas, distillate and residual fuel oils, coal, and LPG they used, representing 28 percent of their actual consumption. (Manufacturers are said to have a fuel-switching capability if they are able to meet their requirements for heat, power, and electricity generation by substituting one energy source for another within 30 days without modifying the equipment that consumes the fuel and if they can resume the same level of production following the switch.)

- Manufacturers required an nonswitchable minimum of 7.0 quadrillion Btu of these energy sources, which was 72 percent of their actual consumption of these fuels. The fuels having the highest nonswitchable minimum requirements were, in order, natural gas, electricity, and coal.

- Manufacturers often used coal and natural gas whenever possible, even though they could have used another energy source instead. Price was apparently the primary reason that manufacturers switched energy sources whenever they were able to do so.

1. Introduction

This report, *Manufacturing Consumption of Energy 1991*, provides estimates on energy consumption in the manufacturing sector of the U.S. economy. These estimates are based on data from the 1991 Manufacturing Energy Consumption Survey (MECS). This survey—administered by the Energy End Use and Integrated Statistics Division, Office of Energy Markets and End Use, Energy Information Administration (EIA)—is the most comprehensive source of national-level data on energy-related information for the manufacturing industries.

Manufacturing Energy Consumption Surveys

To determine how energy is being used in the manufacturing sector, EIA mails Forms 846 A through C to a nationally representative sample of the establishments in the 50 States and the District of Columbia that transform input materials or substances into new products, assemble components, or perform blending operations.[1] In 1991, these establishments numbered approximately 350 thousand, and the MECS sample represented 98 percent of energy use in the U.S. manufacturing sector.

The 1991 MECS is EIA's third survey of the manufacturing sector. Previous manufacturing surveys were conducted in 1986 and 1989 (for reporting years 1985 and 1988, respectively). The next manufacturing survey will be conducted for reporting year 1994, with subsequent MECS's being conducted every 2 years thereafter.

The sample design of the 1991 and 1985 surveys differed somewhat from that of the 1988 survey, which necessitates that care be exercised when comparing estimates from the three surveys. The 1988 sample represented 100 percent of manufacturing energy use, but it included statistical adjustments to account for 2 percent of the population, namely the smallest manufacturing establishments. The 1991 and 1985 samples represented 98 percent of the population, without any statistical adjustment.

EIA conducts the MECS under the authority of the Federal Energy Administration Act of 1974, Public Law 93-275, as amended, and Section 205 of the Department of Energy Organization Act, Public Law 95-91, as amended by Section 3102 of the Omnibus Budget Reconciliation Act of 1986, Public Law 99-509.[2] Section 171 of the Energy Policy Act of 1992 mandates the MECS as a biennial collection.

The Industry Division of the Bureau of the Census collects the data and compiles it for EIA. All data reported to the Bureau of the Census are confidential under the provisions of Section 9, Title 13, of the U.S. Code. EIA gratefully acknowledges the cooperation of the respondents in supplying the information used to produce the estimates in this report.

Organization of This Report

This introductory chapter is followed by a chapter giving an overall understanding of energy consumption in the manufacturing sector, a chapter on some of the more important results of the 1991 MECS on energy consumption and on manufacturing end uses, and a chapter on fuel-switching in the manufacturing sector. Data on manufacturing energy consumption by end use were collected for the first time in the 1991 MECS. This MECS report is the first to include fuel-switching data, which were published under separate cover for previous survey years.

[1]The manufacturing sector is composed of establishments classified in SIC 20 through SIC 39 of the U.S. economy as defined by the Office of Management and Budget (OMB). The manufacturing sector is a part of the industrial division, which also includes mining; construction; and agriculture, forestry, and fishing.

[2]The EIA also conducts energy consumption surveys in the residential, residential transportation, and commercial buildings sectors. These surveys are the Residential Energy Consumption Survey (RECS), the Residential Transportation Energy Consumption Survey (RTECS), and the Commercial Buildings Energy Consumption Survey (CBECS).

The four chapters are followed by several technical appendices:

- Appendix A presents detailed statistical tables, providing measures of data reliability (Relative Standard Errors) as factors in the rows and columns of the data tables rather than separately as in previous reports. To better serve the user community, these tables were released to the public in May 1994 through EIA's electronic bulletin board system.

- Appendix B explains the sample design of and the estimation and implementation procedures for the MECS.

- Appendix C discusses the quality of the data.

- Appendix D compares MECS estimates with those provided by other sources.

- Appendix E presents one of the MECS consumption measures according to international classification codes.

- Appendix F reproduces Forms EIA 846 A through C, which were used to collect the data on which all estimates in this report are based, unless otherwise noted.

- Appendix G describes the major industrial groups and selected industries.

- Appendix H provides a map of the U.S. Census Regions.

- Appendix I presents metric conversion factors.

- Appendix J lists related energy consumption publications for readers interested in earlier MECS publications or consumption reports for other sectors.

These appendices are followed by a glossary of statistical and engineering terms used in this report.

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2. Energy Consumption in the Manufacturing Sector: An Overview

The manufacturing sector of the U.S. economy is composed of approximately 350 thousand establishments. However, the number of establishments is of less significance for the MECS than their share of total energy consumption because these establishments differ so dramatically from each other in their processes and products.

The energy-consuming characteristics of the manufacturing sector differ from those of the residential, commercial building, and residential vehicle sectors in the energy sources manufacturers use, the ways in which they acquire that energy, and the ways in which they use that energy. These complexities require complex measurement techniques.

Manufacturing Establishments

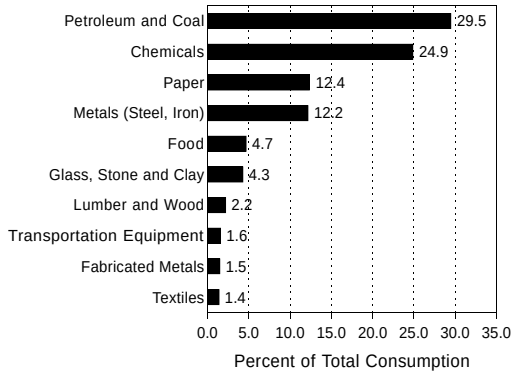
A manufacturing establishment is an economic unit at a single physical location where the mechanical or chemical transformation of materials or substances into new products is performed.[3] These operations are generally conducted in facilities described as plants, factories, or mills and characteristically use power-driven machines and material-handling equipment. Manufacturing also includes such activities as the assembly of components of manufactured products and the blending of materials such as lubricating oil, plastics, resins, or liquors.

An establishment is not necessarily identical to a business concern or firm, either of which may consist of more than one establishment. For example, an automobile manufacturer may be a firm having over 200 establishments, such as stamping plants, auto assembly factories, and gear and axle plants. On the other hand, an automobile manufacturer may be a firm having one establishment, with components coming from several other firms.

Manufacturing establishments fall into the industrial categories listed in the 1987 Standard Industrial Classification (SIC) system, developed by the Office of Management and Budget.[4] That system underlies all establishment-based Federal statistics classified by industry. The SIC system is used to promote the comparability of establishment data describing various facets of the U.S. economy. The levels of classification in the SIC are division, major group, industry group, and industry. The manufacturing sector contains 20 major groups (SIC 20 through SIC 39), 139 industry groups, and 459 industries. Manufacturing establishments are classified into industries based on the value of production of their primary products. See Appendix G for a full description of manufacturing groups and industries used in this report.

Of the 10 largest energy consumers in the manufacturing sector, the two largest were the: (1) petroleum and coal and (2) chemicals and allied products major industry groups (Figure 2.1).

Figure 2.1. Largest Energy Consumers in the Manufacturing Sector, 1991



Source: Table A1 of this report.

[3]Excluded from this definition of manufacturing establishment are construction, electric utilities, mining operations, agricultural production, and forestry and fishery operations.

[4]Office of Management and Budget, *Standard Industrial Classification Manual*, 1987 (Washington, DC, 1987).

Energy Sources

Manufacturers consume large quantities of combustible and noncombustible energy sources. These energy sources include such commonly known ones as natural gas, electricity, coal, residual and distillate fuel oils, and liquefied petroleum gases (LPG), as well as a wide variety of uncommon energy sources. Moreover, some materials, which might be thought of as energy sources, are not counted as energy sources in the manufacturing sector.

Examples of energy sources consumed in the manufacturing sector but not in other sectors of the economy include:

- Pulping liquor, or "black liquor," produced during the transformation of wood to pulp in the Pulp and Paper Industry
- Petroleum coke and still gas resulting from the production of petroleum products in refineries
- Agricultural waste (like rice hulls and orchard prunings), packing crates, discarded tires, and other byproducts and waste materials
- Energy sources that manufacturers produce themselves, such as electricity generated from hydropower, wind power, solar power, and geothermal sources.

On the other hand, materials that are often thought of as energy sources in other sectors are not counted as such in the manufacturing sector. For example, wood consumed to produce paper, build furniture, or manufacture lumber is excluded as an energy source in the MECS. (However, wood that is consumed to produce heat and power is counted as an energy source.)

A further anomaly occurs in petroleum refining in accounting for crude oil. Petroleum refiners are treated differently from other manufacturing establishments in the MECS because their major economic activity is transforming crude oil and other inputs into a wide variety of products. Most of the major products, such as distillate and residual fuel oils, motor gasoline, kerosene, and LPG, are universally recognized and accounted for by consumers as energy sources. However, some of these products, such as asphalt, road oils, wax, lubricating oils, solvents, and specialized petrochemical feedstocks, are not considered to be energy sources.

Energy Sources Used in the Manufacturing Sector

Combustible	Noncombustible
Solids	Steam
Anthracite	Electricity
Bituminous and subbituminous coal	Industrial hot water
Coal coke	Solar energy
Lignite	Hydropower
Agricultural waste	Geothermal energy
Petroleum coke	Wind power
Roundwood (wood cut specifically for fuel use)	
Waste materials (wastepaper, packing materials, etc.)	
Wood chips, bark, and waste	
Other solids	
Gases	
Natural gas	
Acetylene	
Blast furnace gas	
Coke oven gas	
Hydrogen	
Waste and byproduct gases (refinery gas, offgas, fuel gas, vent gas, plant gas, and still gas)	
Other gases	
Liquids	
Distillate fuel oil (numbers 1, 2, and 4 fuel oils and diesel)	
Kerosene	
LPG (ethane, ethylene, propane, propylene, butane, and butylene)	
Motor gasoline	
Pulping or black liquor	
Residual fuel oil (numbers 5, 6, navy special, and bunker c)	
Waste oils and tars	
Other liquids	

The MECS does not count crude oil inputs as consumption in refineries because doing so would duplicate the consumption of the refinery energy products (like gasoline and LPG) that other sectors report. However, the MECS does count the crude oil input to nonenergy products (like asphalt and road oil) because they will not be reported by other sectors. For more information, see Appendix B, "Survey Design, Implementation, and Estimates."

Acquisition of Energy

Energy sources may arrive at an establishment from offsite, or they may be produced onsite. Energy sources produced offsite arrive at an establishment in one of several ways. They may be:

- Purchased directly from an energy supplier and paid for by the consuming establishment
- Purchased and paid for by a central purchasing entity separate from the establishment but delivered directly to the establishment
- Purchased by and transferred from another establishment within the consuming establishment's company
- Delivered from another establishment within a consuming establishment's company, with the consuming establishment being charged for the energy consistent with the company's accounting policy
- Paid for in-kind.

For example, manufacturing establishments usually purchase electricity directly from utilities as other consumers do. In some situations, however, several establishments of the same corporation and physically located in the same geographic area may pool their electricity purchases by having one of the establishments serve as the "central purchaser." In this case, the electricity is transferred from the central purchasing authority to the consuming establishment. Some manufacturers also purchase steam and hot water from a nearby manufacturer or transfer it from an establishment within the same corporation.

Onsite Generation of Electricity in 1991

Onsite generation of electricity accounted for 15 percent of all the electricity generated (both offsite and onsite) in the manufacturing sector in 1991. Of this amount, electricity from:

- Cogeneration made up 88 percent
- Conventional generation from the fossil fuels made up 9 percent
- Generation from renewable energy made up 3 percent.

Three major groups accounted for 84 percent of the onsite generation of electricity:

- Paper and Allied Products (54 billion kilowatthours)
- Chemicals and Allied Products (41 billion kilowatthours)
- Petroleum and Coal Products (13 billion kilowatthours).

Manufacturers produce some of the energy they use onsite, as a byproduct of a manufacturing process, from onsite coal mines or gas or oil wells, and through the generation of electricity. Coke oven gas, which is produced as a byproduct when manufacturing coke from coal, is one example of energy being produced as a byproduct of a manufacturing process. A second example is hydrogen, which is produced as a byproduct when the electrolysis of brine (salt water, a nonenergy material) produces chlorine and caustic soda as the main products. Both coke oven gas and hydrogen are used as energy sources.

Manufacturers generate electricity onsite in three ways:

- Cogeneration (the production of electrical energy and another form of useful energy, such as steam, through the sequential use of energy)
- Conventional generation using combustible fuels
- Generation using solar power, wind power, hydropower, and geothermal sources.

Use of Energy Sources

Manufacturers use energy sources in two major ways. The most widely understood use is to produce heat and power and to generate electricity. Heat, power, and electricity consumption can be subdivided into three major end uses: indirect use (boiler fuel), direct process uses, and direct non-process uses.[5] Boiler fuel is used to transform one source of energy into another (like steam). Direct process uses include energy for motors, ovens, strip heaters, and kilns. Direct non-process uses include facility lighting and space-conditioning equipment.

The second way in which manufacturers use energy is as a raw material input to the manufacturing process or for some other purpose other than for heat, power, and electricity generation.[6] (These purposes are referred to as "nonfuel uses" in this report.) For example, coal is consumed to produce coal coke. Also, natural gas is processed to extract ethane, propane, and butane. These gases, in turn, are frequently used as raw material input to produce fertilizers, pharmaceutical preparations, and other products.

Three General Measures of Energy Consumption

The MECS uses three general measures of energy consumption in the manufacturing sector: (1) Primary Consumption of Energy for All Purposes, (2) Total Inputs of Energy for Heat, Power, and Electricity Generation, and (3) Consumption of Offsite-Produced Energy for Heat, Power, and Electricity Generation. These measures are used for different purposes:

- The Primary Consumption measure is most appropriate in discussions of the amount and impact of total U.S. energy consumption.

- The Total Inputs measure is most useful in discussions of how energy use in the manufacturing sector compares with energy use in the residential and commercial sectors.

- The Consumption of Offsite-Produced Energy measure is used to continue the data series, "Purchased Fuels and Electric Energy," which was previously collected for EIA by the Bureau of the Census as a supplement to its Annual Survey of Manufactures. These data were published for the reporting years 1974 through 1981.

Primary Consumption of Energy for All Purposes is the most comprehensive measure of energy consumption and represents the first use of energy sources, no matter whether they are consumed as a fuel or as a nonfuel (mainly raw material):

- It includes all energy produced offsite.

- It includes all energy produced onsite from nonenergy materials (such as sawdust from furniture production, hydrogen from electrolysis of brine, and peanut shells from peanut processing).

- It includes net electricity, net steam, and net hot water.[7]

- It excludes all energy sources produced onsite as a result of the use of another energy source.

For example, the Primary Consumption measure includes the coal (an energy source purchased offsite) used at steel works as a raw material to produce coal coke. However, the measure excludes the coal coke (an energy source produced onsite as a result of the use of another energy source).

[5]The 1991 MECS was the first collection of national-level end-use data.

[6]Energy consumed as a raw material is frequently called a feedstock, although that terminology most often refers to petroleum-based inputs and natural gas.

[7]Net electricity, net steam, and net hot water are the sum of purchases, transfers in, and onsite production from renewables minus the quantities sold and transferred out.

Total Inputs of Energy for Heat, Power, and Electricity Generation is a less comprehensive measure of energy consumption because it measures only the energy used for its energy content:

- It includes all energy sources used to produce heat and power and to generate electricity, whether produced offsite or onsite.
- It includes net electricity, net steam, and net hot water.
- It excludes all energy sources used as raw material or other nonfuel uses.

For example, the Total Inputs measure includes coal coke consumed onsite as a fuel, but it excludes the coal that was consumed as a raw material input to produce the coke.

Consumption of Offsite-Produced Energy for Heat, Power, and Electricity Generation is the most restrictive measure of the three:

- It includes all energy sources purchased or transferred from offsite to produce heat and power and to generate electricity.
- It excludes all energy produced onsite.
- It excludes all energy sources used as raw materials or for other nonfuel purposes.

Components and Measures of Combustible Energy Consumption

Each of the three general measures of energy consumption covers different components of combustible energy consumption, which has six components:

1. Energy produced offsite and consumed as a fuel
2. Energy produced offsite and consumed for nonfuel purposes
3. Energy produced onsite from nonenergy inputs and consumed as a fuel
4. Energy produced onsite from nonenergy inputs and consumed for nonfuel purposes
5. Energy produced onsite from energy products and consumed as a fuel
6. Energy produced onsite from energy products and consumed for nonfuel purposes.

Primary Consumption includes Components 1, 2, 3, and 4. Total Inputs includes Components 1, 3, and 5. Total Consumption of Offsite-Produced Energy includes only Component 1. (None of the three measures explicitly includes Component 6 to avoid double counting.)

Specific Measures of Energy Consumption

In addition to the three general measures of energy consumption, this report provides specific measures related to electricity, steam, and hot water consumption.

Embodied energy for electricity is the energy electricity suppliers use to generate the electricity consumed at the site.[8] During the generation process, large energy losses occur:

- When heat is converted into mechanical energy for turning electric generators
- When the power plant uses electricity for its own purposes, such as pumping water into elevated reservoirs in pumped-storage hydroelectric plants
- When electricity is transmitted and distributed from the power plant to the consumer.[9]

[8]Other products from EIA commonly use the term "primary energy" to denote energy measures that incorporate input energy used to generate electricity. The MECS uses "embodied energy for electricity" for this concept to avoid confusion with the term "Primary Consumption of Energy."

[9]Although energy losses also occur during the production of natural gas, fuel oil, and district heat, they are so small compared with those occurring during the production of electricity that they are not considered in measuring primary energy consumption in this report.

However, measuring the amount of the energy losses is complicated because their amount varies from year to year and from utility plant to utility plant, depending on the conversion process, the particular mix of input energy sources used in generation, and the efficiency of the utility plant. Since collecting data on these factors for each utility plant would be unreasonable within the framework of EIA consumption surveys, the amount of energy consumed to produce the electricity consumed onsite in any given year can only be estimated.

Evaluating the Energy Value of Electricity Consumption

Electricity consumption can be expressed in terms of either

- physical units, most commonly kilowatthours
- thermal units, most commonly British thermal units (Btu).

The physical unit is meant to give a clear understanding of the amount of a particular energy source being used, while the thermal unit is a measure of convenience used to aggregate or compare various energy sources measured in different physical units. Converting kilowatthours of electricity to Btu is not a trivial issue, because the amount of input energy needed to create a kilowatthour of electricity is far greater than the amount of useful energy in the kilowatthours at its point of use. Therefore, meaningful conversions of electricity use from kilowatthours to Btu can be given in terms of:

- Site (point-of-use) electricity, at the universal value of 3,412 Btu per kilowatthour. This value is useful to engineers, energy managers, and others trying to improve energy efficiency.
- Embodied (primary) electricity, at a value that reflects the content of the energy inputs used to produce the electricity. This rate is most useful to policymakers and analysts who are considering global resources and environmental issues.

Estimates of embodied electricity should be treated with caution. They should be considered rough alternative measures to site energy as indicators of the importance of electricity as a manufacturing energy source.

EIA bases this estimate on the approximate annual amount of combustible fuels (coal, natural gas, and petroleum products) used by steam-electric generating plants, which generate most of the Nation's electricity.[10] In 1991, U.S. steam-electric utility plants are estimated to have used approximately 10,352 Btu of conventional-fuel energy to generate 1 kilowatthour of electricity—or approximately 3.03 Btu of conventional-fuel energy to generate 1 Btu of electricity, since 3,412 Btu equals 1 kilowatthour of electricity.[11] Accordingly, in this report, estimates of site electricity consumption in kilowatthours can be converted to estimates of embodied energy consumption by using 10,352 as the conversion factor. For example, in Table A1, Part 1, the Food and Kindred Products Industry group consumed 49,536 million kilowatthours of electricity. Multiplying this estimate by 10,352 Btu per kilowatthour would yield 513 trillion Btu, the amount of embodied energy used to generate that amount of electricity.

Estimates of embodied electricity can only be approximations of the amount of energy actually used to generate electricity, especially in the manufacturing sector, because many manufacturers use energy sources other than the combustible fuels. For example, the electricity-intensive industries, such as aluminum, are concentrated in areas where electricity can be generated from energy sources other than conventional fuels, usually hydropower. Thus, the accuracy of the conversion factor varies across industry groups.

Electricity demand is the amount of electricity actually consumed onsite, regardless of where or how it was produced. It is a useful measure of electricity consumption without regard to the consumption of other energy sources. Electricity demand is estimated in this report as the sum of electricity purchases, transfers in, and total onsite generation minus the quantities of electricity sold or transferred offsite.

[10]The fossil fuels, especially coal, provide the principal energy sources for the generation of electricity. Nuclear and hydroelectric power are used to a lesser extent, with wood/waste, wind, geothermal, and solar energy supplying only a small amount of energy for electricity generation.

[11]"Table A8. Approximate Heat Rates for Electricity," *Monthly Energy Review*, August 1994, p. 165.

Net electricity is estimated for each manufacturing establishment as the sum of purchased electricity, transfers in, and generation from noncombustible renewable resources minus the quantities of electricity sold and transferred offsite. Thus net electricity excludes the quantities of electricity generated or cogenerated onsite from combustible energy sources. The estimates of net electricity appear in the estimates of Total Primary Consumption for All Purposes (Table A1) and Total Inputs of Energy for Heat, Power, and Electricity Generation (Table A4).

Electricity receipts is the amount of electricity purchased and transferred into the establishment. This measure is used so that the MECS estimates of offsite-produced energy will be consistent with the Census Bureau's definition of "purchased fuels and electricity," on which the Bureau of the Census collected and published data from 1974 through 1981. The estimates for Electricity Receipts appear in the estimates of Total Consumption of Offsite-Produced Energy for Heat, Power, and Electricity Generation (Table A5).

Net steam is the sum of purchases, transfers in, and generation from renewable energy sources minus the quantities sold and transferred out.

Net hot water is the sum of purchases and transfers in, minus the quantities of hot water sold and transferred out.

Estimates of net steam and net hot water are not shown separately in the MECS but are included in the "Other" column of tables that show Primary Consumption and Total Inputs. The estimates of Offsite-Produced Energy for Heat, Power, and Electricity Generation include the steam and hot water purchased by and transferred to a manufacturing establishment in order to be consistent with the Census Bureau's definition of "purchased fuels and electricity."

3. Energy Consumption in the Manufacturing Sector, 1991

In 1991, the amount of energy consumed in the manufacturing sector was as follows:

- Primary Consumption of Energy for All Purposes was 20.3 quadrillion Btu of energy, or about one-third of the total end-use energy consumed by the U.S. economy.
- Total Inputs of Energy for Heat, Power, and Electricity Generation were 15.0 quadrillion Btu.

The end uses for which manufacturing establishments consumed most of this energy were boiler fuel, direct processing, and direct non-processing (facility support).

Primary Consumption of Energy for All Purposes

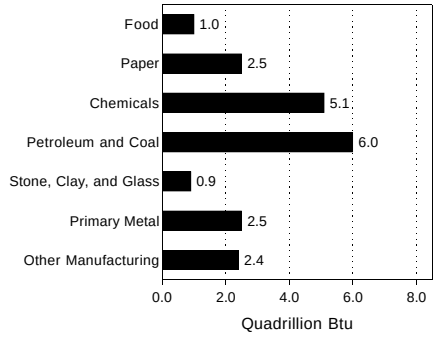
The amount of Primary Consumption of Energy for All Purposes in 1991 was 20.3 quadrillion Btu, compared with 20.1 quadrillion Btu in 1988 and 17.5 quadrillion Btu in 1985. The shares of consumption for each of the commonly known energy sources remained stable during the 6-year period:

- The share for natural gas was 30 percent in 1991, 29 percent in 1988, and 30 percent in 1985.
- The share for net electricity was 12 percent in all 3 years.[12]
- The share for coal was 10 percent in 1991, 12 percent in 1988, and 14 percent in 1985.
- The share for liquefied petroleum gas (LPG) was 8 percent in 1991 and 5 percent in 1985 and 1988.
- The share for other energy sources was 41 percent in 1991, 42 percent in 1988, and 40 percent in 1985.[13]

Six industry groups accounted for 88 percent (17.8 quadrillion Btu) of Primary Consumption of Energy for All Purposes: food and kindred products; paper and allied products; chemicals and allied products; petroleum and coal products; stone, clay, and glass products; and primary metals (Figure 3.1).

About two-thirds of Primary Consumption of Energy for All Purposes (13.9 quadrillion Btu) was used to produce heat and power and to generate electricity, with about one-third (6.4 quadrillion Btu) being consumed as raw material input (Table A3).

Figure 3.1. Primary Consumption of Energy for All Purposes by Major Industry Group, 1991



Source: Table A1 of this report.

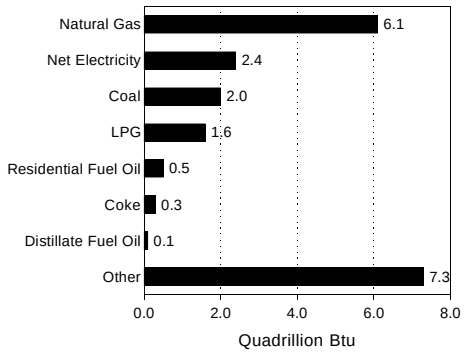
[12]"Net electricity" is the sum of purchases, transfers in, and generation from noncombustible renewable resources, minus quantities sold and transferred out.

[13]Changes in shares for coal and LPG from 1988 to 1991 were statistically significant at the 0.05 level. Changes in shares for natural gas, net electricity, and other energy sources were nonsignificant.

The most common energy sources—natural gas, net electricity, coal, liquefied petroleum gas (LPG), residual and distillate fuel oil, and coke—made up 64 percent of Primary Consumption. Making up the remaining 36 percent of Primary Consumption were still gas, waste gas, petroleum coke, pulping liquor, and other energy that respondents indicated they had used as Primary Energy, as well as crude oil inputs to such materials as asphalt and road oil (Figure 3.2).

Natural Gas. Natural gas was the energy source most heavily consumed at the manufacturing site in 1991, accounting for 30 percent of Primary Consumption. Natural gas consumption is heavily concentrated in the chemicals and allied products major industry group, where it is consumed as a fuel and as a feedstock. This major industry group accounted for about 36 percent (2.2 quadrillion Btu) of the Primary Consumption of natural gas (Table A1). About one-fourth of the natural gas consumed by the chemicals and allied products major industry group (0.6 quadrillion Btu) was used as an energy raw material (Table A3). Natural gas is used as a raw material in the preparation of numerous products, but one of the heaviest uses is for manufacturing nitrogenous fertilizers.

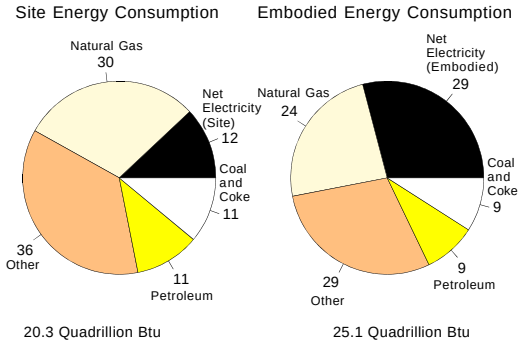
Figure 3.2. Primary Consumption of Energy for All Purposes by Energy Source, 1991



Source: Table A1 of this report.

Electricity. Net electricity was the second most heavily consumed single energy source by manufacturers in 1991, accounting for 12 percent of site Primary Consumption (2.4 quadrillion Btu).[14] However, taking into account the amount of energy used to generate the site net electricity (the embodied energy consumption for net electricity), net electricity accounted for 29 percent of site energy consumption (Figure 3.3).

Figure 3.3. Percent of Primary Consumption in Terms of Site and Embodied Electricity, 1991



Source: Table A1 of this report.

Four major industry groups consumed 54 percent (1.3 quadrillion Btu) of Primary Consumption of net electricity: food and kindred products, paper and allied products, chemicals and allied products, and primary metal industries. Of these, the primary metal major industry group, which includes primary aluminum, was the heaviest consumer. The primary aluminum industry uses large quantities of electricity to produce aluminum ingots from alumina. In 1991, net electricity provided 77 percent of the aluminum industry's site energy consumption. (Taking into account the energy used to generate that site electricity, it accounted for 91 percent of the industry's embodied energy consumption.)

Coal. The 1991 Primary Consumption of coal was 2.0 quadrillion Btu. Coal is heavily consumed by the blast furnaces and steel mills industry to produce coke. Coking operations accounted for 0.8 quadrillion Btu, or 40 percent of Primary Consumption of coal.

[14]Unless otherwise specified, all estimates of electricity consumption shown in this report are given in terms of site energy.

LPG. Liquefied petroleum gases (LPG) are consumed mostly as a raw material by manufacturers. The largest users are chemical industries that use LPG as petrochemical feedstock. An example is the production of ethylene from ethane. Of the total 1991 Primary Consumption of 1.6 quadrillion Btu, 1.5 quadrillion Btu (94 percent) was used as a raw material.

Distillate and Residual Fuel Oils. The Primary Consumption of distillate and residual fuel oils continued at a relatively low level in 1991. Residual fuel oil accounted for only 0.5 quadrillion Btu and distillate fuel oil, 0.1 quadrillion Btu. Total fuel oil consumption accounted for only about 3 percent of Primary Consumption, which also was the case in both the 1985 and 1988 MECS.

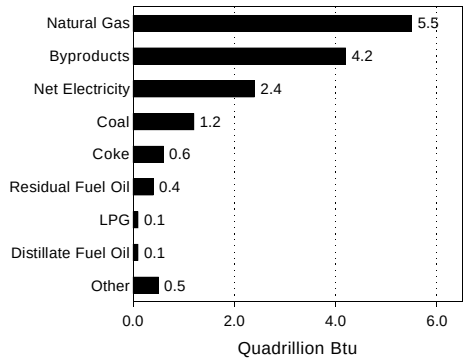
Other Energy Sources. Other energy sources accounted for 36 percent (7.3 quadrillion Btu) of Primary Consumption. Those energy sources included net steam and other energy that respondents indicated was used as a fuel and raw material input (4.4 quadrillion Btu). In addition, the estimate has been supplemented by the quantity of energy consumed by the petroleum refining industry to produce final products that are not normally considered to be energy sources (asphalt, road oil, solvents, lubricants, and waxes). Those products accounted for 40 percent (2.9 quadrillion Btu) of the other energy sources. (See Appendix B for a discussion of the rationale of this procedure.)

Total Inputs of Energy

The amount of Total Inputs of Energy for Heat, Power, and Electricity Generation in 1991 was 15.0 quadrillion Btu, compared with 15.5 quadrillion Btu in 1988 and 13.6 quadrillion Btu in 1985. Between 1988 and 1991, the shares of consumption for each of the commonly known energy sources remained stable:

- The share for natural gas was 34 percent in 1988 compared with 37 percent in 1991.
- The share for net electricity was 15 percent in 1988 compared with 16 percent in 1991.
- The share for coal and coke was 13 percent in 1988 compared with 12 percent in 1991.
- The share for petroleum products was 6 percent in 1988 compared with 4 percent in 1991.
- The share for byproducts was 28 percent in 1988 and 1991.
- The share for other energy sources was 3 percent in 1988 compared with 4 percent in 1991.[15]

Figure 3.4. Total Input Energy for Heat, Power, and Electricity Generation, 1991



Source: Tables A4 and A6 of this report.

The shares for the various energy sources in 1985 cannot be compared with shares for 1988 and 1991 because data on the amount of byproduct fuels consumed in 1985 were published only in aggregate form.

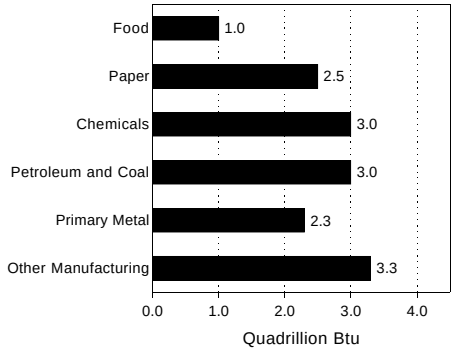
Of the eight specific types of energy measured by Total Inputs, natural gas was the dominant energy source, followed by byproduct fuels (Figure 3.4). Energy sources produced offsite made up 72 percent of Total Inputs of Energy for Heat, Power, and Electricity Generation. Fuels produced onsite made up the remaining 28 percent.

[15]Changes in shares for natural gas, coal and coke, petroleum products, and other energy sources from 1988 to 1991 were statistically significant at the 0.05 level. Changes in shares for net electricity and byproducts were nonsignificant.

Consumption by Major Industry Group

The major industry groups consuming the most energy for heat, power, and electricity generation were food and kindred products, paper and allied products, chemicals and allied products, petroleum and coal products, and primary metal industries (Figure 3.5). Industries vary in the proportion of energy they use for heat, power, and electricity generation and the proportion they use for raw materials. Some industries, like the food and kindred products and the paper and allied products industries, consume large amounts of energy for heat, power, and electricity generation and small amounts of energy for raw material. Other industries, such as the chemicals and petroleum industries, consume large amounts of energy as raw material.

Figure 3.5. Total Input Energy for Heat, Power, and Electricity Generation by Major Industry Group, 1991



Source: Table A4 of this report.

Food and Kindred Products. In the food and kindred products major industry group, the 1991 estimates of Primary Consumption and Total Inputs are nearly identical at 1.0 quadrillion Btu. This close correspondence is because the food industry consumes virtually all its energy as a fuel to process food for distribution and consumes negligible amounts of energy as a raw material.

Paper and Allied Products. Estimates of Primary Consumption and Total Inputs are also similar for the paper and allied products major industry group (about 2.5 quadrillion Btu for each) because this group, too, consumes only small amounts of energy sources as energy raw material. It should be noted that the primary raw material input for the production of pulp and paper is wood. However, pulping wood is not counted as an energy source in the MECS because it is considered by manufacturers to be a nonenergy raw material input. Therefore, both Primary Consumption and Total Inputs include wood byproducts.

Chemicals and Petroleum Industries. The chemicals and allied products and the petroleum and coal products major industry groups clearly illustrate these industries' heavy use of energy as a raw material. The 1991 Primary Consumption for chemicals and allied products was 5.1 quadrillion Btu, of which 2.4 quadrillion Btu was consumed as an energy raw material. Total Inputs for chemicals and allied products (3.0 quadrillion Btu) excludes the energy consumed as a raw material. The petroleum and coal products major industry group was quite similar, with a Primary Consumption of 6.0 quadrillion Btu, of which 3.0 quadrillion Btu was consumed for nonfuel use, as raw material input to nonenergy products.

Byproduct Fuels

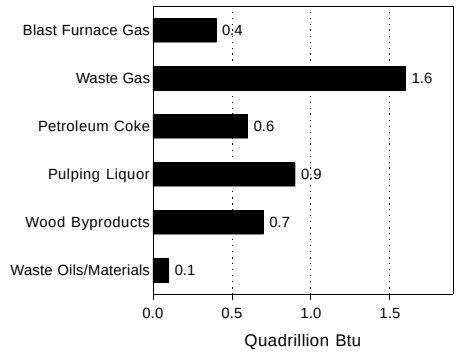
Byproduct fuels—blast furnace gas, waste gas, petroleum coke, pulping liquor, wood byproducts, and waste oils/materials—made up 28 percent of Total Inputs of Energy for Heat, Power, and Electricity Generation (Figure 3.6). Industries differ in the amount of byproduct energy they use, with the blast furnace, petroleum refining, and paper and pulp industries being the largest consumers of byproduct fuels.

Blast Furnace Industry. The blast furnace industry consumed 1.6 quadrillion Btu of input energy in 1991. This industry commonly produces two byproduct fuels—blast furnace and coke oven gas. Blast furnace gas is a combustible waste gas generated in a blast furnace when iron ore is being reduced with coke to metallic iron. In addition, most steel works produce much of their own coke. Coke oven gas is a combustible mixture of gases produced by the carbonization of coal in a coke oven. These gases are "recycled" and consumed onsite as a fuel.

Of the total input energy consumption of this industry, 27 percent (0.4 quadrillion Btu) was provided by these by-product energy sources (Table A6).

Petroleum Refineries. The 1991 input energy requirement for the petroleum refining industry was 2.9 quadrillion Btu. That energy was consumed as a fuel to refine crude oil into useful products. Waste gas (still gas) and petroleum coke are byproducts of the petroleum refining process. Waste gas is any form or mixture of gas produced in refineries by distillation, cracking, reforming, and other refining processes. The principal constituents of waste gas are methane, hydrogen, ethane, ethylene, propane, propylene, butane, and butylene. Petroleum coke is a solid residue that is high in carbon content and low in hydrogen. It is the final product of thermal decomposition in the condensation process in cracking crude oil. Some of these byproducts are sold, but most are recycled into the refining process and consumed as a fuel. In 1991, these byproducts accounted for 1.8 quadrillion Btu, or 62 percent of the total input energy requirement of the petroleum refining industry.

Figure 3.6. Byproduct Fuels Consumed by Manufacturers by Energy Source, 1991



Source: Table A6 of this report.

Paper and Allied Products Industries. The paper and allied products industries use enormous amounts of wood to produce paper. Byproducts of the wood used to produce paper consist of pulping liquor and wood chips, bark, and wood waste. Pulping liquor is the alkaline spent liquor removed from the digester in the process of chemically pulping wood. After evaporation, the liquor is burned in a recovery furnace that provides heat and permits the recovery of certain basic chemicals from the liquor. Nearly all pulping liquor is consumed onsite, as are most of the wood byproducts. Total 1991 input energy for this major industry group was 2.5 quadrillion Btu. Of that amount, pulping liquor accounted for 0.9 quadrillion Btu and wood chips, bark and wood waste, for 0.3 quadrillion Btu. Thus, 48 percent of the total input energy requirement of the paper and allied products major industry group was met by these byproduct energy sources.

End Uses for Heat, Power, and Electricity

In 1991, 65 percent of the Total Inputs of Energy for Heat, Power, and Electricity Generation in the manufacturing sector was allocated to three groups of end uses: indirect uses (mainly boiler fuel), direct process uses, and direct non-process uses. The remaining 35 percent of energy inputs was unallocated. The 1991 MECS was the first collection of national-level end-use data.

End-Use Consumption of Energy

The manufacturing sector used 9.7 quadrillion Btu of natural gas, electricity, coal, residual and distillate fuel oils, and LPG to produce the heat, power, and electricity needed for:

- Boiler fuel, which is used to transform one source of energy into another (like steam)
- Direct process uses, including use in motors, ovens, strip heaters, and kilns
- Direct non-process uses, including facility heating, ventilation, and air-conditioning (HVAC); facility lighting, other facility support; onsite transportation; electricity generation; and other miscellaneous uses.

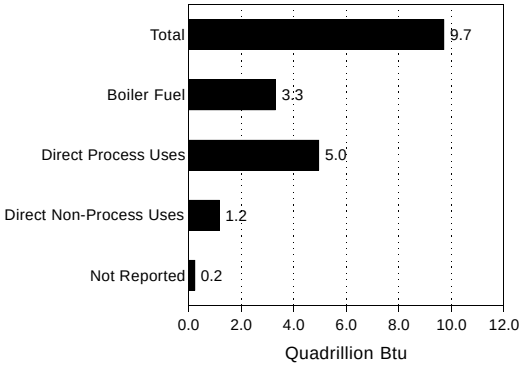
The manufacturing sector as a whole used the most energy for direct process uses (Figure 3.7).

Boiler Fuel

Approximately one-third (3.3 quadrillion Btu) of reported 1991 end-use consumption was consumed as boiler fuel, energy that was then transformed into steam or some other energy source. This transformation of energy describes the largest specific end use of reported energy consumed by manufacturing establishments.

Transformation of energy is not usually considered an energy use because steam has subsequent end uses. Steam, the predominant output from industrial boilers, has multiple uses in most manufacturing establishments and is, therefore, difficult for manufacturers to measure and quantify since the energy content depends upon both temperature and pressure. In the surgical and medical instruments industry, for example, steam can be used to sterilize medical products such as sutures and syringes. Meanwhile, high-pressure steam can also be used to produce electricity or can be used by other industrial processes or non-processes that require thermal energy.

Figure 3.7. Consumption of Energy for Heat, Power, and Electricity Generation by Manufacturing End Use, 1991

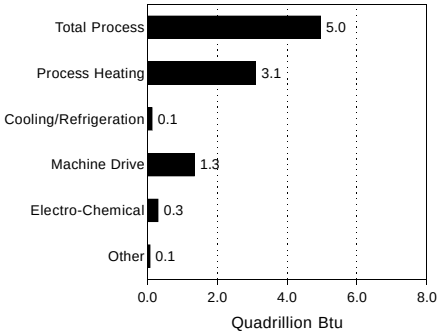


Source: Table A36 of this report.

Direct Process End Uses

In 1991, over half (5.0 quadrillion Btu) of reported end-use consumption was used to transform raw material inputs into production outputs. The MECS identified four distinct direct processes—process heating, process cooling/refrigeration, machine drive (motors),[16] electro-chemical processes—and a group of other unspecified processes. The three most energy-intensive direct process end uses were process heating, machine drive, and electro-chemical processes (Figure 3.8).

Figure 3.8. Consumption of Energy for Heat, Power, and Electricity Generation by Manufacturing Direct Process End Use, 1991



Source: Table A36 of this report.

Process heating, which accounted for 62 percent (3.1 quadrillion Btu) of all reported direct process consumption, encompasses numerous uses. For example:

- The aluminum industry uses process heating to hold molten aluminum in crucibles after the electro-chemical process (the reduction process) of splitting alumina into molten aluminum metal and oxygen.
- The steel industry uses process heating to melt scrap metal in electric-arc furnaces.
- The food industry uses process heating to dry food residual (such as yeast extract) for resale as livestock feed.

Machine drive, used for equipment such as industrial air compressors and pumps, consumed 1.3 quadrillion Btu (27 percent) of reported direct process consumption and represented the second largest reported direct process use of energy. Of that 1.3 quadrillion Btu, electricity accounted for 1.2 quadrillion Btu (88 percent) of consumption. Electro-chemical use of energy ranked third in the reported consumption of energy for direct process uses. Over 0.3 quadrillion Btu of electricity, concentrated in the primary metal and chemicals and allied products industries, were consumed in that process. Of that amount of purchased and generated electricity, the primary metal industries

[16]Machine drive transforms thermal or electrical energy into mechanical energy.

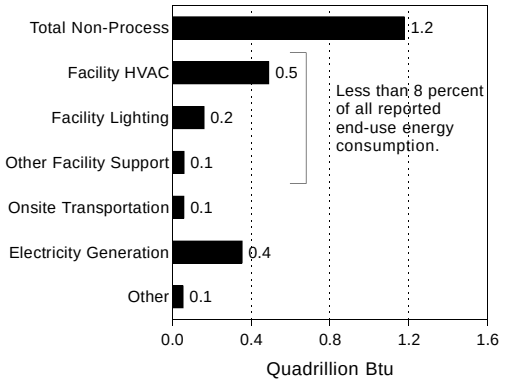
accounted for 229 trillion Btu (63 percent) and the chemicals and allied products industries consumed 114 trillion Btu (32 percent). Within the primary metal industries, the primary aluminum industry consumed 216 trillion Btu (60 percent) of electro-chemical use. This industry uses the electro-chemical process to reduce alumina to molten aluminum metal and oxygen (Table A38).

To improve the energy efficiency of their direct process operations, manufacturing establishments participated in various demand-side management (DSM) and other energy management programs (Table A40). From 1989 through 1991, their activities and percent of participation, expressed in terms of the total input energy use represented by participating establishments, were as follows: installing or retrofitting motors to achieve better energy efficiency (36 percent), improving the efficiency of process heating (34 percent), and improving the efficiency of process cooling (15 percent).

Direct Non-Process End Uses

Of the 9.7 quadrillion Btu of consumption for which end uses were reported, only 1.2 quadrillion Btu was designated for direct non-process uses. Less than 8 percent (0.7 quadrillion Btu) of energy consumption in manufacturing establishments was directly related to facility use (Figure 3.9). Process uses of energy affect some facility-related use of energy. Heat that radiates from manufacturing processes may negate, or restrict, facility HVAC use of energy. For example, glass melters found in the glass industries create a large amount of heat energy that is then transferred to the surrounding working environment. Since cooling that environment is not usually considered economically viable, the proximity of the manufacturing process may reduce the likelihood that the enclosed manufacturing floorspace is conditioned. In addition, those indirect transfers of radiant heat from processing uses to the surrounding environment are not measured.

Figure 3.9. Consumption of Energy for Heat, Power, and Electricity Generation by Manufacturing Direct Non-Process End Use, 1991



Source: Table A36 of this report.

To improve the energy efficiency of their direct non-process operations, manufacturing establishments participated in various DSM and other energy management programs (Table A40). From 1989 through 1991, their activities and percent of participation, expressed in terms of the total input energy use represented by participating establishments, were as follows: improving the efficiency of facility lighting (36 percent) and installing equipment to improve facility HVAC systems (23 percent).

Industry Patterns of Energy Consumption for Different End Uses

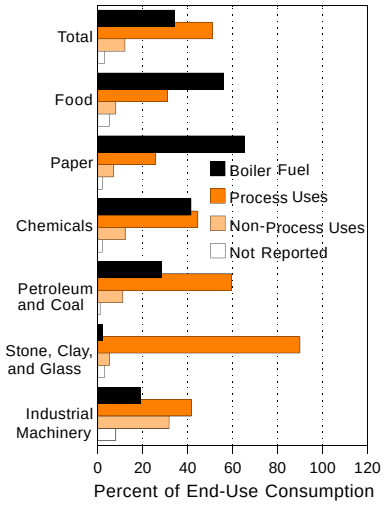
Since the production process is commonly considered the driving force behind the manufacturing sector, most industries consume most of their energy for direct process uses and consume relatively little for non-process uses. In 1991, direct non-process uses accounted for roughly 1.2 quadrillion Btu, or 12 percent of reported energy consumption. One of the heaviest users of energy for direct processes was the stone, clay, and glass major industry group, which consumed 0.7 quadrillion Btu (90 percent of all the energy it consumed) for direct process uses. This industry group is a heavy user of process heating, which is an energy-intensive end use.

Other industries, however, used most of the energy they consumed for heat, power, and electricity for boiler fuel, such as the paper and allied products industries and the pulping and paper-making processes industries. The paper and allied products industries, which reported 1.2 quadrillion Btu for end-use consumption, reported consuming 66 percent of its reported inputs as boiler fuel, and only 26 percent in direct process uses and 7 percent in direct non-process uses, with the remaining 1 percent undiscerned. That configuration of consumption was also characteristic

of the pulping and paper-making processes, where large quantities of steam are required to remove water from paper sheets (Figure 3.10).

Most industries use only a small percentage of the energy they consume for non-process end uses. However, in those industries where assembly-type manufacturing takes place in large, environmentally controlled buildings, it can be quite a large percentage. Examples are the furniture and fixtures industries (32 percent), transportation equipment industries, such as automobile plants (25 percent), or computer and office equipment industries (43 percent).

Figure 3.10. Consumption of Energy for Heat, Power, and Electricity Generation by Major Industry Groups and Major End Uses, 1991



Source: Table A36 of this report.

Unallocated End-Use Consumption of Energy

In addition to the 9.7 quadrillion Btu of the most common energy sources that manufacturers consumed for boiler fuel, direct process uses, and direct non-process uses, manufacturers consumed 5.3 quadrillion Btu of energy for which end uses were not assigned. Eight byproduct energy sources formed the major components of the 5.3 quadrillion Btu of unallocated end-use consumption: waste gas, pulping liquor (black liquor), blast furnace/coke oven gases, petroleum coke, coal coke, wood byproducts, waste oils/materials, and net steam (Figure 3.11).

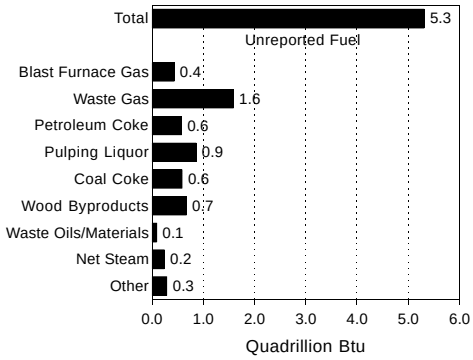
While consumption of byproducts was not allocated to a specific end use, those energy sources generally have a finite number of uses at a manufacturing establishment. For example:

- Coal coke is generally consumed as a fuel for its heat content and as a reducing agent for smelting iron ore in the blast furnaces and steel mills industry, accounting for 0.5 quadrillion Btu (92 percent) of the unallocated coal coke.

- Pulping liquor, generated onsite at paper industry establishments, is generally consumed in recovery boilers to generate heat and recover catalysts for use in the pulping process.

- Waste gas is generally consumed for process heating in petroleum refineries, according to a 1984 American Petroleum Institute study.[17]

Figure 3.11. Unreported End-Use Fuels Consumed for Heat, Power, and Electricity Generation, 1991



Source: Tables A4, A6, A36, and D2 of this report.

[17]Chemical and Engineering News, *Energy Use by Petroleum Industry*, June 9, 1986.

Summary

In 1991, the Primary Consumption of Energy for All Purposes in the manufacturing sector was 20.3 quadrillion Btu of energy, compared with 20.1 quadrillion Btu in 1988. About two-thirds of this amount was used to produce heat and power and to generate electricity, with about one-third being consumed as raw material input to produce nonenergy products. The most common energy sources—natural gas, net electricity, coal, LPG, residual and distillate fuel oil, and coke—made up 64 percent of Primary Consumption.

The amount of Total Inputs of Energy for Heat, Power, and Electricity Generation was 15.0 quadrillion Btu in 1991, compared with 15.5 quadrillion Btu in 1988. The byproduct fuels—blast furnace gas, waste gas, petroleum coke, pulping liquor, wood byproducts, and waste oils/materials—made up 28 percent of Total Inputs.

End-use allocation was collected for about 65 percent of Total Inputs (9.7 quadrillion Btu). This consumption was allocated to three groups of end uses: indirect uses, mainly boiler fuel (3.3 quadrillion Btu); direct process uses, including use in motors, ovens, strip heaters, and kilns (5.0 quadrillion Btu); and direct non-process uses, including facility HVAC, facility lighting, other facility support, onsite transportation, electricity generation, and other miscellaneous uses (1.2 quadrillion Btu). Manufacturers consumed an additional 5.3 quadrillion Btu of energy for which end uses were not assigned.

4. Manufacturer Capability To Switch Fuels

Manufacturers can often best adapt to changes in economic conditions, energy supply interruptions, and other constraints on energy use by switching fuels. For the MECS, manufacturers are said to have a fuel-switching capability if they are able to meet their requirements for heat, power, and electricity generation by substituting one energy source for another within 30 days without modifying the equipment that consumes the fuel and resuming the same level of production following the switch.

Although all manufacturers have certain minimum requirements for energy sources that cannot be replaced by another energy source, many manufacturers have some fuel-switching capability. The degree of a manufacturer's capability depends only on the characteristics of the equipment and practical limitations to switching, such as binding take-or-pay agreements with energy suppliers and environmental regulations that limit the amounts of potential replacements that could have been consumed. Much of the fuel-burning equipment that manufacturers use is capable of burning more than one energy source.

The 1991 MECS determined fuel-switching capability for six commonly known energy sources and looked at the extent to which manufacturers exercised their ability to choose the mix of energy sources at their discretion.

Nonswitchable Minimum Requirements

Generally, a manufacturing establishment uses a certain quantity of an energy source that cannot be replaced by any other energy source, at least not within a 30-day period. The reasons for nonswitchable quantities are as varied as the types of production environments themselves. Among the practical limitations to switching are the characteristics of the establishment and the equipment itself, which would require, at the very least, significant modifications disruptive to production. Other switching deterrents are existing energy-supply contracts and environmental restrictions. In addition, the physical properties of certain energy sources could produce a desirable or harmful effect on the product.

For example, consider a manufacturing plant that consumed 2.0 million cubic feet of natural gas to produce automobile bodies. Of that amount, 500 thousand (0.5 million) cubic feet of natural gas was nonswitchable because it was consumed in paint-drying ovens that required natural gas. Using any other energy source would have changed the tint of the pigments in the paint, rendering the products unsalable. The remaining 1.5 million cubic feet of natural gas was switchable because it was consumed in a boiler that could burn either natural gas or residual fuel oil, and the switch between those two energy sources could have taken place within a few hours.

In 1991, manufacturers required an nonswitchable minimum of 7.0 quadrillion Btu of electricity receipts,[18] natural gas, distillate and residual fuel oils, coal, and liquefied petroleum gas (LPG), 72 percent of actual consumption of these fuels (Figure 4.1). This amount represents actual consumption decreased by the quantity of the energy sources that would no longer have been required if all ascertained switching from that energy source had occurred. This amount also includes the quantity of 1991 consumption for which switching capability was not ascertained.

The following are manufacturers' nonswitchable requirements for the most common energy sources, stated as a percentage of the actual consumption of each energy source:

- Electricity: 98 percent of actual consumption
- Natural gas: 65 percent of actual consumption

[18]The estimate of electricity receipts represents those quantities of electricity that were produced offsite and available onsite for consumption, but it does not include electricity generated onsite, nor has it been adjusted to account for any quantities that might have been resold or transferred to another establishment.

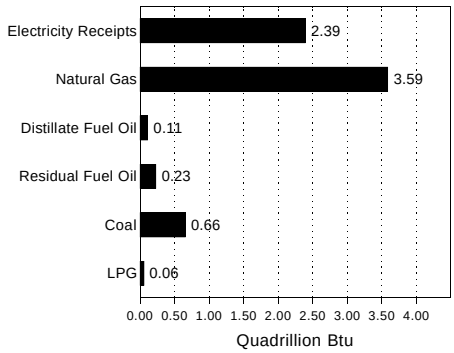
- Distillate fuel oil: 80 percent of actual consumption

- Residual fuel oil: 55 percent of actual consumption

- Coal: 55 percent of actual consumption

- LPG: 53 percent of actual consumption.

Figure 4.1. Nonswitchable Minimum Requirements for Selected Fuels, 1991



Source: Table A52 of this report.

Fuel-Switching Capability

In 1991, manufacturers had the capability to switch 2.8 quadrillion Btu of the most common energy sources, representing 28 percent of actual consumption. The energy sources for which fuel-switching capability is most desirable are the petroleum-based fuels. Since the mid-1970's, concern about U.S. dependency on crude oil imports and adherence to environmental restrictions have prompted manufacturers to concentrate on reducing their consumption of petroleum-based fuels.

According to the Bureau of the Census, manufacturers' 1978 consumption of residual and distillate fuel oils accounted for 17 percent of total offsite-produced energy for heat, power, and electricity generation.[19] By 1991, those same petroleum-based energy sources accounted for only 4 percent of the total. This substantial decrease was likely due to manufacturers' replacement of petroleum-based fuels with other energy sources. By 1991, manufacturers had little capability remaining to replace petroleum-based fuels with other energy sources.

Natural gas has long been viewed as a prime alternative to petroleum-based fuels because of its widespread availability, supply reliability, clean-burning quality, and reduced storage capacity. However, a fuel-switching capability for natural gas is also necessary because of occasional supply disruptions. For example, natural gas production at the wellhead may be disrupted or the supplier may not be able to deliver the required amount of natural gas. Moreover, the natural gas supply may be interrupted during periods of extreme cold weather, when residential and commercial customers receive priority service at the sacrifice of manufacturers. Finally, the demand for natural gas sometimes exceeds supply in certain parts of the country, especially in the Northeast and Midwest, forcing manufacturers to use some other energy source for awhile.

The energy sources that had the greatest potential for switching were natural gas, with coal a distant second (Figure 4.2). The following were manufacturers' fuel-switching capabilities for the most common energy sources:

- About 17.0 billion kilowatthours of electricity receipts could have been replaced by other energy sources, 2 percent of actual consumption (Table A53). The switching potential for electricity is quite limited because most manufacturing equipment is not designed to permit switching between electricity and a combustible energy source. Most of the capability to replace electricity by combustible energy sources is in the form of redundant combustors that can be used in place of electric-powered equivalents.

- About 1.9 trillion cubic feet of natural gas was switchable, 35 percent of actual consumption. The primary replacement energy sources for natural gas were distillate fuel oil, coal coke, and residual fuel oil (Table A54). No single energy source could have decreased the consumption of natural gas even halfway to its minimum required level of 3.5 trillion cubic feet, but the dominant single replacement source, distillate fuel oil, could have replaced 0.7 trillion cubic feet (40 percent) of the natural gas that was switchable.

[19]Before 1985, Total Inputs for Heat, Power, and Electricity Generation were not collected. However, for those earlier years, the Bureau of the Census did tabulate total consumption of offsite-produced energy for heat, power, and electricity generation, which is a key part of Total Inputs because most petroleum-based fuels are produced offsite.

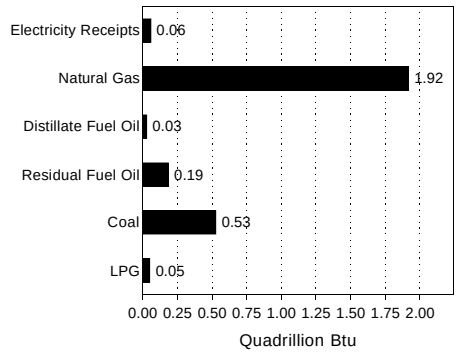
- About 4.8 million barrels of distillate fuel oil was switchable, 20 percent of actual consumption. Natural gas was the dominant replacement source for distillate fuel, capable of replacing 3.2 million barrels (Table A55).

- About 29.3 million barrels of residual fuel oil was switchable, 45 percent of actual consumption, with natural gas capable of replacing 19.5 million barrels (Table A56).

- About 23.6 million short tons of coal (45 percent of actual consumption) could have been replaced by other energy sources (Table A57).

- About 13.3 million barrels of LPG (47 percent of actual consumption) was switchable, with natural gas capable of replacing 11.4 million barrels (Table A58).

Figure 4.2. Switchable Quantities for Selected Fuels, 1991



Source: Table A52 of this report.

Discretionary Fuel Use

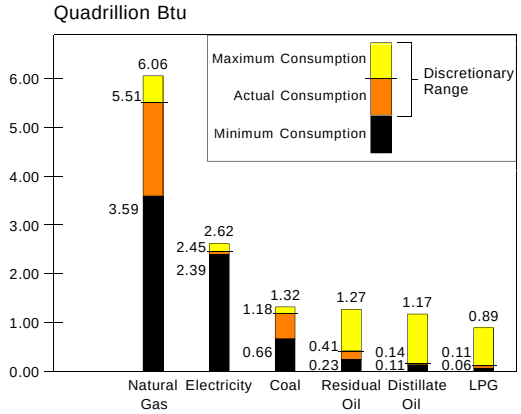
Fuel-switching capability allows manufacturers substantial flexibility in choosing their mix of energy sources. The consumption of a given energy source can be maximized if all possible switching into that energy source were to take place. At the other extreme, consumption can be minimized if all possible switching from that energy source were to take place. (This value is the nonswitchable minimum requirement discussed earlier.) The interval defined by these maximum and minimum limits represents the discretionary range of consumption for an energy source, resulting from fuel-switching capability. Actual consumption lies within that discretionary range. A preference for a given energy source is indicated when its actual consumption approaches its maximum consumption potential, as in the case of both natural gas and coal (Figure 4.3). Conversely, a preference for other energy sources is indicated when actual consumption approaches its minimum required level.

For example, one manufacturer in the 1991 MECS used 3.0 million Btu of a given energy source, 1.0 million Btu of which could have been replaced by some other energy source and 2.0 million Btu of which could not have been replaced. In addition, the manufacturer could have used the given energy source to replace 2.0 million Btu of other energy sources. If the manufacturer had chosen to use the given energy source whenever possible, consumption of the energy source would have been at the maximum consumption level of 5.0 million Btu. If the manufacturer had chosen to use a substitute energy source whenever possible, the manufacturer's consumption of the given energy source would have been at the minimum consumption level of 2.0 million Btu. Thus, the maximum potential is 3.0 million Btu above the minimum level, and this amount (3.0 million Btu) represents the discretionary range of consumption. Since the actual consumption is 1.0 million Btu above the minimum level, the depth into the discretionary range is 1.0/3.0 or 33 percent, which is the discretionary use rate of the given energy source.

One of the more interesting summary statistics that can be developed from the estimates of actual consumption, minimum consumption, and maximum consumption is the *discretionary use rate*. The discretionary use rate is a measure of the extent to which manufacturers elected to consume a given energy source when they could have consumed some other energy source, given their fuel-switching capabilities and production levels of 1991. (See Appendix B for an explanation and formula of the discretionary use rate.)

If manufacturers always choose to use an energy source whenever possible, the discretionary use rate for that energy source would be 100 percent. On the other hand, if manufacturers choose to minimize their consumption of a given energy source by always using other energy sources whenever possible, the discretionary use rate would be 0 percent.

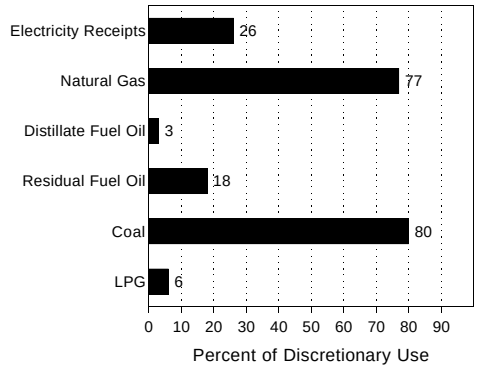
Figure 4.3. Manufacturers' Discretionary Ranges of Consumption Resulting from Fuel-Switching Capability, 1991



Source: Table A52 of this report.

A look at the discretionary use rates for the commonly known fuels shows that manufacturers often used natural gas and coal whenever possible in 1991. In contrast, they seldom used distillate fuel oil and LPG, even when they could have done so (Figure 4.4). The discretionary use rates for the commonly known energy sources are as follows:

Figure 4.4. Discretionary Use Rates by Selected Fuels, 1991



Source: Table A52 of this report.

- Coal ranked highest in discretionary use with a robust rate of 80 percent. The consumption of coal was close to its short-term maximum level, given the levels of production in 1991 (Table A52).

- Natural gas ranked second in discretionary use with a rate of 77 percent.

- Electricity had a relatively low use rate of 26 percent, indicating that manufacturers preferred other energy sources when available. Electricity receipts rated a distant second to natural gas in terms of fuel demand by manufacturers, as they totaled 2.5 quadrillion Btu (0.7 trillion kilowatt-hours).

- The extremely low discretionary use rates for distillate fuel oil (3 percent) and LPG (6 percent) indicate that manufacturers generally avoided consuming these energy sources whenever possible.

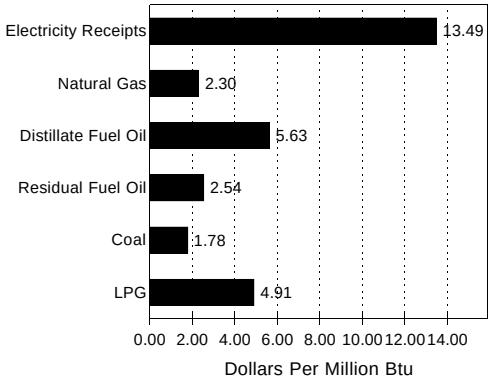
- The discretionary use rate for residual fuel oil was 18 percent. Although that use rate was considerably higher than those for distillate fuel oil and LPG, it was still low enough to indicate a preference for other energy sources over residual fuel oil.

Price would appear to be the primary reason that manufacturers exercised their option to switch fuels (Figure 4.5). For example, the discretionary use of coal was due in part to the fact that manufacturers had no price incentive to switch to any other energy sources. At $1.78 per million Btu, the national price of coal was substantially below that of any competing energy source.

Furthermore, manufacturers had no price incentive to replace natural gas with distillate fuel, even though that switching capability existed in 1991. Nationally, the price of natural gas stood at $2.30 per million Btu, while the price of distillate fuel oil was $5.63 per million Btu (Table A25). The price of distillate fuel was uniformly higher than the price of natural gas in the four Census Regions, with the difference never being less than $2.00 per million Btu.

In certain geographic regions of the United States, however, price incentives existed to replace natural gas with residual fuel oil. Residual fuel oil could have replaced 0.6 trillion cubic feet (34 percent) of the 1.9 trillion cubic feet of natural gas that was switchable. At $2.54 per million Btu, the national price of residual fuel oil was only marginally higher than that of natural gas. However, in the Northeast Census Region, the reported average price of natural gas hit $3.39, compared with $2.90 for residual fuel oil, thereby yielding a gas-oil price ratio of 1.17. The gas-oil price ratios were 1.10, 0.87, and 0.90 for the Midwest, South, and West Census Regions, respectively. Although price incentives existed in the Northeast and Midwest to switch from natural gas to residual fuel oil, these two regions consumed 0.7 trillion cubic feet of switchable natural gas, of which 0.3 trillion cubic feet (35 percent) could have been replaced by less expensive residual fuel oil in 1991 (Table A54). In these regions, manufacturers chose natural gas over residual fuel oil despite favorable price incentives.

Figure 4.5. Average National Prices of Selected Purchased Fuels, 1991



Source: Table A25 of this report.

Summary

For the MECS, manufacturers are said to have a fuel-switching capability if they are able to meet their requirements for heat, power, and electricity generation by substituting one energy source for another within 30 days without modifying the equipment that consumes the fuel and if they can resume the same level of production following the switch.

In 1991, manufacturers required an nonswitchable minimum of 7.0 quadrillion Btu of electricity, natural gas, distillate and residual fuel oils, coal, and LPG, which was 72 percent of their actual consumption of these fuels. The fuels having the highest nonswitchable minimum requirements were, in order, natural gas, electricity, and coal.

Manufacturers had the capability to switch 2.8 quadrillion Btu of these energy sources, representing 28 percent of their actual consumption. Natural gas was the energy source having the greatest potential for switching. Manufacturers often used coal and natural gas whenever possible, even though they could have used another energy source instead. Price would seem to be the primary reason that manufacturers exercised their option to switch fuels.