CHANGES IN ENERGY INTENSITY IN THE MANUFACTURING SECTOR, 1985-1991

Mark A. Schipper, Energy Information Administration[1]
Michael J. Margreta, Energy Information Administration
Jean M. Paananen, Pacific Northwest Laboratories

INTRODUCTION

In 1991, the manufacturing sector, on average, consumed more energy per value of shipments than in either 1988 or 1985, showing an increase in purchased energy intensity of four percent from 1988 to 1991. This increased energy requirement is a function of a myriad of internal and external factors. Among the numerous internal factors that could influence energy intensity are changes in manufacturers' internal mix of products produced during these years, and changes in the technologies and processes used to produce them. Economic conditions represent one of the most influential external factors. The decline of energy prices following the 1991 Gulf War and the weakening of the Organization of Petroleum Exporting Countries (OPEC) removed one of the most commonly cited business incentives for investing in projects to manage energy usage—cost control.

This paper, based on the 1985, 1988, and 1991 Manufacturing Energy Consumption Surveys (MECS), presents statistics about changes in energy consumption per constant dollar of value of shipments. The 1991 MECS is the third survey conducted, with earlier surveys gathering information on 1985 and 1988 energy consumption patterns. The information in this paper continues the data series[2] on changes in energy intensity based on information collected by the two earlier surveys. Data for the MECS were collected on an establishment-by-establishment basis and reported based on the Standard Industrial Classification (SIC) system.

In this paper, energy intensity is defined as the ratio of energy consumption per unit of output. Output is measured as the constant dollar of value of shipments and receipts, and two measures of energy consumption are presented in British thermal units (Btu): Offsite-Produced Energy and Total Inputs of Energy. Variations in these ratios denote changes in energy efficiency. A *decrease* in energy intensity from one period to another suggests an *increase* in energy efficiency, and vice versa. Energy efficiency, however it is computed and tracked, is a still an arbitrary concept. For this paper, the criteria for tracking efficiency—changes in energy intensity—are based on industry knowledge and current methodological analyses.

SURVEYING THE MANUFACTURING SECTOR

The manufacturing sector consists of establishments that use mechanical or chemical processes to transform material or substances into new products. An establishment is usually at a single physical location and is often called a plant, factory, or mill. It ordinarily uses power-driven machines and equipment for handling materials. Its products may be final products that consumers will purchase, such as an automobile or a chair, or they may be goods for use by other manufacturers, such as parts for automobile engines or rolls of upholstery fabric. A manufacturing establishment may also assemble parts or perform blending operations.

The Federal Office of Management and Budget developed procedures for classifying manufacturing and non-manufacturing establishments into industry classes. These procedures are known as the SIC system. Each industry class consists of establishments that produce similar types of good or services.

Establishments that fall into SIC categories 20 (Food and Kindred Products) through 39 (Miscellaneous Manufacturing Industries) make up the manufacturing sector. Each of these two-digit *major groups* is further separated into three-digit *industry groups* and four-digit *industries* based on their primary products. For example, SIC 325 (Structural Clay Products) is one of nine industry groups in SIC 32 (Stone, Clay, Glass, and Concrete Products). SIC 3253 (Ceramic Wall and Floor Tile) and SIC 3255 (Clay Refractories) are two of the four-digit industries that make up SIC 325.

Revision of SIC Codes

The Office of Management and Budget (OMB) maintains and periodically updates the SIC system to ensure the classification system remains up-to-date, accurately reflecting current economic activities. Revisions consist of adding new categories as well as removing or combining old categories. Examples include creating separate categories for electronic computers and computer storage devices, and combining categories for primary lead, primary zinc, and other primary nonferrous metals into a single category. The latest SIC revision was completed in 1987. (See box at right.)

Industry Coverage

The MECS is a nationally representative sample of manufacturing establishments classified by SIC codes 20 through 39. In addition to these major manufacturing groups, SICs 01-07 (Agriculture), SICs 15-17 (Construction), and SICs 10-14 (Mining Activities) are outside the scope of the survey.

The Energy Information Administration (EIA) constructed the MECS questionnaire and designed the sampling plan. The Census Bureau conducted the survey, assuring that each MECS response is covered by the same confidentiality provisions as apply to all Census Bureau data collections (Section 9, Title 13 of the U.S. Code). Response is mandatory. Only sworn Census agents have access to individual survey responses.

Energy-Intensity Ratios Based on 1987 Definitions of Industry

The Standard Industrial Classification system underwent a major revision in 1987, resulting in several industries being redefined. The MECS estimates of energy consumption—Total Inputs of Energy and Offsite-Produced Energy—and the Annual Survey of Manufactures (ASM) estimates of value of shipments for 1988 and 1991 conform to the revised industry classifications. The corresponding estimates for 1985 were based on the 1972 classification system.

Calculating the changes in energy intensity for major groups requires comparability between the base and end-year estimates. Accordingly, the 1985 estimates of energy consumption and the corresponding estimates of value of shipments, were re-estimated using the 1987 classification system. These re-estimates were used to calculate the energy-intensity ratios. However, all index estimates appearing in this paper for years preceding 1987 are based on the 1972 classification system, while 1987 and later year estimates are based on the 1987 classification system.

The sample design allows attachment of economic data obtained by other agencies (e.g., Census Bureau, Bureau of Economic Analysis). This matching is possible on an establishment-by-establishment basis. Data for this paper include economic information for a specific establishment and energy consumption data for that same establishment. The Bureau of the Census and the Bureau of Economic Analysis (BEA) provide economic data. These data combine to provide the information required to develop energy-intensity estimates.

The MECS selects from the entire manufacturing sector through its relationship with the Census of Manufactures (CM) and Annual Survey of Manufactures (ASM) conducted by the Bureau of the Census. That is, the MECS is subselected from the ASM mail sample, which in turn was subsampled from the CM. The sizes of the sample for the three MECS are as follows:

- 1991 -- 16,054 mailed questionnaires
- 1988 -- 12,065 mailed questionnaires
- 1985 -- 11,684 mailed questionnaires

ENERGY CONSUMPTION AND PRODUCTION OUTPUT

Measures of Energy Consumption

This paper presents information on two measures of energy consumption: (1) Total Inputs of Energy for Heat, Power, and Electricity Generation, and (2) Offsite-Produced Energy for Heat, Power, and Electricity Generation. Both measures provides specific information on how manufacturing establishments use energy.

Total Inputs of Energy for Heat, Power, and Electricity Generation is the more comprehensive measure of energy consumption. For the first time, this paper includes intensities based on this measure of consumption. This measure:

- Includes all energy sources—either produced onsite or offsite—used to produce heat and power, and to generate electricity.
- Includes net electricity, net steam and net industrial hot water.

- Excludes energy sources used as raw material or for other nonfuel uses (e.g., coal used as an input to produce coke or wood used to make furniture).

Consumption of Offsite-Produced Energy for Heat, Power, and Electricity Generation is a more limited measure of energy consumption collected by the MECS. This measure:

- Includes all energy sources purchased or transferred from offsite and consumed onsite to produce heat and power and to generate electricity.
- Excludes all energy produced onsite and consumed as fuel.
- Excludes energy sources used as raw material or for other nonfuel purposes.

Offsite-Produced Energy consumption for heat, power, and electricity generation continues the Bureau of the Census series of *purchased fuels and electricity* energy data. When compared with Total Inputs of Energy measures, it shows how dependent particular industry groups are on energy purchased or transferred from offsite sources. For example, the Paper and Allied Products Industry (SIC 26) consumed 22.32 thousand Btu for every constant dollar value of output in 1991. Of this total consumption, only 13.90 thousand Btu came from Offsite-Produced Energy. Much of the remainder of the energy consumed was in the form of black liquor, a combustible byproduct of the pulping process.

Value of Shipments as Output Indicator

The calculation of changes in intensity requires a measure of production output for each SIC. One possible measure is the number of physical units produced; however, physical quantities are not the best measure for two reasons. First, most manufacturing establishments produce more than a single product line. For example, in SIC 22 (Textiles) a single establishment may produce not only bedspreads, but also tablecloths and dishcloths. Because these are different products, with different process steps and energy requirements, summing them to a single measure of total output is not possible. For the same reason, it is not possible to sum the physical outputs of all industries to obtain an estimate of total manufacturing sector output.

Second, summing different products into a single output indicator might be appropriate if information on energy consumption associated with each product line were available, but manufacturers rarely, if ever, monitor and record energy data by product or process. This information could suggest the use of a particular production process, possibly affecting their competitive status. An associated difficulty is that the MECS and ASM obtain data by establishments, not by products. Combining information from different sources would be nearly impossible if product rather than a controllable economic variable represented output.

Value of shipments is the output measure used to calculate energy intensity. Summing value of shipments both across and between SIC categories provides output measures for each SIC and for the manufacturing sector as a whole. Value of shipments is also the production measure used by the Census Bureau when assigning establishments into a particular SIC category. Use of this measure further assures consistency between the MECS and the ASM.

Using value of shipments as an output indicator also has drawbacks. One problem is that the product values change over time. Inflation can cause these changes. Rising values of shipments over time are not necessarily associated with increased production but instead could reflect general price increases that affect all products and services to varying degrees.

The value of shipments estimate used in the calculation of energy-intensity ratios is adjusted for fluctuations in product value over time. Using BEA price deflators at the industry level, each individual establishment's value of shipments for 1985, 1988, and 1991 is adjusted to represent 1987 constant dollars.[3] By adjusting for changes in price of goods, aggregate output measures of value of shipments are made comparable over the time periods of interest.

Further, re-estimation of value of shipments statistics is required to ensure comparability with estimates of energy consumption. Rather than adjust the value of shipment estimates provided by the ASM, this paper uses the direct estimates of value of shipments from the MECS sample, which required a 100 percent matching of each individual MECS establishments with their corresponding ASM value of shipments. Direct estimation of both consumption and value of shipments statistics from each of the MECS samples results in comparable energy-intensity ratios.

A second problem with using value of shipments as an output measure is that, over time, the contribution of each SIC

to total output may vary. This variation can occur within and between two-digit groups. What might at first glance appear to be an increase or decrease in energy intensity could, in fact, be simply a response to changing demand for particular products. *Structural shift* is the term that describes these changes in relative importance. (See box for more discussion of structural shift.)

To estimate structural shifts, EIA developed intensities for each SIC for both Offsite-Produced and Total Inputs of Energy consumption, which are presented in Tables 3 and 4. The structurally adjusted intensity change is based on the assumption that no structural shift occurred since 1985, and that the same mix of output was available in 1988 and 1991 as in 1985.

Changes in Energy Intensity

Manufacturers are in the business of producing physical units of output for consumption by end users or other manufacturers. One goal of production is to consume as few inputs as possible to produce a quality output. Specifically, if energy requirements are reduced relative to output, each unit of output has become less energy intensive. This improvement is an increase in energy efficiency.

This paper presents the percent changes in energy intensity from 1985 to 1988, 1988 to 1991, and 1985 to 1991. This information is presented for only 15 of the 20 two-digit major groups. Sample sizes for earlier surveys were not sufficient to produce representative estimates for the remaining 5 two-digit major groups or 10 four-digit industries. This paper includes 1985 and 1988 survey data recalculated to include all establishments in their 1987 SIC classification. This recalculation precludes comparisons between published reports but provides a solid basis for the analysis of product mix change.

An Example of Structural Shift

Consider a manufacturing economy composed of only two subsectors: A and B. Subsector A is characterized as an energy-intensive subsector, while B is less energy intensive. In 1985, production from subsector A was 100 units, with a corresponding consumption of 500 thousand Btu, resulting in an energy intensity of the 5 thousand Btu per unit of output. For the same year, subsector B also produced 100 units while consuming 200 thousand Btu, resulting in an energy intensity of 2 thousand Btu per unit of output.

In this economy, then, manufacturers produced a total of 200 units of goods and consumed a total of 700 thousand Btu, yielding an energy intensity of 3.5 thousand Btu per unit of output. Subsector A and subsector B each represented 50 percent of all manufacturing output.

Six years later, in 1991, this fictional manufacturing economy responds to the current production demand. Instead of an equal share of manufacturing output, each subsector has accordingly realigned their production shares. The total output remains at 200 units, but subsector B now represents 80 percent (160 units) of the manufacturing economy, with A supplying the remaining 20 percent (40 units). Although production shares have undergone realignment, energy intensities for subsectors A and B remain unchanged, which means that energy intensities for A and B are 5 and 2 thousand Btu per unit of output, respectively. However, aggregation of A and B to the manufacturing level results in an energy intensity of 2.6 thousand Btu per unit of output—320 Btu from A and 200 Btu from B to produce 200 units of goods. Direct comparison of 1985 ratio with the 1991 unadjusted manufacturing energy-intensity ratio shows an improvement in energy efficiency of 26 percent—apparently a dramatic improvement in efficiency.

In this illustration, rather than improving energy efficiency through plant improvements or other means, the manufacturing economy has structurally shifted towards less energy-intensive products. To adjust for such shifts, end-year intensities are re-estimated with the base-year (1985) production mix. Since each subsector's energy intensities are unchanged, the manufacturing economy's adjusted 1991 energy intensity is also unchanged, illustrating that energy efficiency was stagnant (0 percent) over the past 6 years. Thus, the entire improvement in energy efficiency (26 percent) is due to the effect of structural shift within the manufacturing economy since 1985.

Like earlier reports, this paper calculates changes in intensity as the difference between the energy requirements per constant dollar value of shipments for one period and those for an earlier period. The energy-intensity ratios included

in Tables 1 through 4 provide the information to calculate the changes in intensity. These ratios indicate Btu consumption (in thousands) for each constant dollar of output. A percent change in efficiency that is positive indicates an *increase* in energy efficiency, whereas a negative percent change indicates a *decrease* in energy efficiency.

It is important not to compare changes in intensity between different SICs but instead to compare the changes within an individual SIC. The output from one manufacturing establishment is often used as an input by another establishment. To some extent, the value of shipments of the second seller duplicates that of the first seller. For this reason, the sum of individual SIC value of shipments will not result in the value of shipments for the entire manufacturing sector.

Structural Shifts

Energy consumption per unit of output depends not only on how efficiently products are manufactured, but also on what products are manufactured. Over time, new products (e.g., personal computers, compact discs) become available and replace older technology (e.g., typewriters, phonograph records). Analysis of structural shift identifies this change in demand, and the impact it has on manufacturing establishments. Energy consumption by an establishment or major group changes in response to increased (or decreased) demand for products. For the first time, this report identifies the importance these changes in relative output have on energy intensity. Tables 3 and 4 identify Offsite-Produced and Total Inputs of Energy intensities adjusted for structural shift.

As the 1988 or 1991 unadjusted intensities are applied to the original 1985 constant dollar value of shipment distribution of the three-digit group, the result is the amount of energy that would be required to produce the same distribution of 1985 product, but with 1988 or 1991 energy intensities. If an adjusted intensity is less than the unadjusted intensity for that same year, this indicates a movement within the two-digit group toward more energy-intensive products over time. At the same time, if the adjusted intensity is greater than the unadjusted intensity, movement within the group was toward less energy-intensive products. Comparison of unadjusted and adjusted percent changes in energy intensity indicates how much of the unadjusted change was due to changes in efficiency and how much was due to structural shifts within manufacturing.

Table 1. Site Intensity of Offsite-Produced Energy in Major Manufacturing Groups and Selected Industries, 1985, 1988, and 1991[a]

SIC Code	Major Group and Industry	Energy-Intensity Ratios (thousand Btu/constant dollar)			Change in Energy Efficiency (percent)		
		1985	1988	1991	1985-1988	1988-1991	1985-1991
20	Food and Kindred Products	2.53	2.79	2.64	-10.07	5.27	-4.27
21	Tobacco Products	NA	NA	NA	NA	NA	NA
22	Textile Mill Products	4.49	4.54	4.67	-1.12	-2.87	-4.02
23	Apparel and Other Textile Products	NA	NA	NA	NA	NA	NA
24	Lumber and Wood Products	NA	NA	NA	NA	NA	NA
25	Furniture and Fixtures	1.37	1.48	1.39	-8.24	6.07	-1.67
26	**Paper and Allied Products**	**12.27**	**11.29**	**13.90**	**7.97**	**-23.09**	**-13.28**
2621	**Paper Mills**	**24.27**	**23.22**	**26.63**	**4.31**	**-14.66**	**-9.71**
2631	**Paperboard Mills**	**36.31**	**33.89**	**39.47**	**6.65**	**-16.47**	**-8.72**
27	Printing and Publishing	NA	NA	NA	NA	NA	NA
28	Chemicals and Allied Products	11.85	11.28	11.55	4.80	-2.34	2.58
2819	Industrial Inorganic Chemicals, nec	19.08	19.68	21.14	-3.13	-7.41	-10.77
2821	Plastics Materials and Resins	10.22	10.42	9.80	-1.97	6.00	4.14
2869	Industrial Organic Chemicals, nec	22.66	19.75	21.01	12.82	-6.40	7.25
2873	Nitrogenous Fertilizers	79.89	90.60	111.64	-13.41	-23.22	-39.75
29	Petroleum and Coal Products	7.63	7.83	8.33	-2.60	-6.41	-9.18
2911	Petroleum Refining	7.75	7.87	8.63	-1.30	-9.60	-11.02
30	Rubber and Misc. Plastic Products	3.04	3.05	2.62	-0.48	14.31	13.90
31	Leather and Leather Products	NA	NA	NA	NA	NA	NA
32	Stone, Clay, and Glass Products	15.52	16.39	17.35	-5.61	-5.82	-11.76
3241	Hydraulic Cement	81.04	78.06	86.89	3.68	-11.32	-7.22
33	Primary Metal Industries	13.84	13.66	13.40	1.31	1.89	3.18
3312	Blast Furnaces and Steel Mills	22.32	23.21	21.96	-3.97	5.37	1.61
3334	Primary Aluminum	45.21	41.11	37.94	9.07	7.72	16.09
34	Fabricated Metal Products	2.18	2.33	2.24	-6.84	3.82	-2.76
35	Industrial Machinery and Equipment	1.20	1.10	1.00	7.84	9.04	16.17
36	Electronic and Other Electric Equipment	1.15	1.21	1.05	-4.83	12.94	8.74
37	Transportation Equipment	1.04	0.97	1.00	6.78	-2.68	4.28
38	Instruments and Related Products	1.05	0.91	0.89	13.21	2.53	15.41
39	Misc. Manufacturing Industries	1.25	1.27	1.08	-1.45	14.87	13.64
	Total	4.35	4.26	4.44	2.05	-4.08	-1.95

NA=Not available. Data are included in higher-level totals.

NOTE: Positive percent change indicates a *decrease* in energy intensity and an *increase* in energy efficiency. Negative percent change indicates an *increase* in energy intensity and a *decrease* in energy efficiency.

Source: Energy Information Administration, *Manufacturing Consumption of Energy 1991*, DOE/EIA-0512(91), Washington, DC, 1994, *Manufacturing Energy Consumption Survey: Consumption of Energy, 1988*, DOE/EIA-0512(88), Washington, DC, 1991, and *Manufacturing Energy Consumption Survey: Consumption of Energy, 1985*, DOE/EIA-0512(85), Washington, DC, 1988.

[a]Site energy includes only those Btu available to the establishment. It specifically includes electricity available for the manufacturing establishment (3,412 Btu/kWh).

Table 2. Site Intensity of Total Inputs of Energy in Major Manufacturing Groups and Selected Industries, 1985, 1988, and 1991[b]

SIC Code	Major Group and Industry	Energy-Intensity Ratios (thousand Btu/constant dollar)			Change in Energy Efficiency (percent)		
		1985	1988	1991	1985-1988	1988-1991	1985-1991
20	Food and Kindred Products	2.73	2.93	2.73	-7.31	6.96	0.16
21	Tobacco Products	NA	NA	NA	NA	NA	NA
22	Textile Mill Products	4.50	4.52	4.69	-0.71	-3.64	-4.37
23	Apparel and Other Textile Products	NA	NA	NA	NA	NA	NA
24	Lumber and Wood Products	NA	NA	NA	NA	NA	NA
25	Furniture and Fixtures	1.59	1.74	2.04	-10.03	-17.06	-28.81
26	**Paper and Allied Products**	**20.17**	**18.78**	**22.32**	**6.90**	**-18.84**	**-10.63**
2621	**Paper Mills**	**38.18**	**36.50**	**41.42**	**4.40**	**-13.47**	**-8.48**
2631	**Paperboard Mills**	**64.25**	**59.43**	**62.34**	**7.51**	**-4.90**	**2.98**
27	Printing and Publishing	NA	NA	NA	NA	NA	NA
28	Chemicals and Allied Products	13.16	12.57	13.13	4.50	-4.43	0.26
2819	Industrial Inorganic Chemicals, nec	21.41	20.70	21.67	3.29	-4.66	-1.21
2821	Plastics Materials and Resins	13.62	11.47	10.75	15.78	6.31	21.09
2869	Industrial Organic Chemicals, nec	26.91	23.43	26.77	12.93	-14.25	0.52
2873	Nitrogenous Fertilizers	80.63	94.09	112.62	-16.69	-19.69	-39.66
29	Petroleum and Coal Products	20.36	22.86	21.87	-12.25	4.33	-7.39
2911	Petroleum Refining	21.54	24.09	23.45	-11.85	2.67	-8.85
30	Rubber and Misc. Plastic Products	3.05	3.06	2.64	-0.55	13.83	13.36
31	Leather and Leather Products	NA	NA	NA	NA	NA	NA
32	Stone, Clay, and Glass Products	15.84	16.50	17.67	-4.16	-7.14	-11.59
3241	Hydraulic Cement	84.09	79.58	91.49	5.36	-14.96	-8.78
33	Primary Metal Industries	21.54	20.20	19.66	6.21	2.67	8.71
3312	Blast Furnaces and Steel Mills	45.46	42.73	40.93	6.00	4.22	9.97
3334	Primary Aluminum	45.23	41.02	37.75	9.30	7.97	16.53
34	Fabricated Metal Products	2.19	2.34	2.24	-6.61	3.99	-2.35
35	Industrial Machinery and Equipment	1.19	1.10	1.00	7.88	8.63	15.83
36	Electronic and Other Electric Equipment	1.15	1.21	1.05	-5.11	13.09	8.64
37	Transportation Equipment	1.03	0.97	1.04	5.92	-7.99	-1.60
38	Instruments and Related Products	1.04	0.92	0.89	11.83	2.77	14.27
39	Misc. Manufacturing Industries	1.31	1.28	1.11	2.47	13.31	15.46
	Total	6.06	5.96	6.15	1.70	-3.35	-1.60

NA=Not available. Data are included in higher-level totals.

NOTE: Positive percent change indicates a *decrease* in energy intensity and an *increase* in energy efficiency. Negative percent change indicates an *increase* in energy intensity and a *decrease* in energy efficiency.

Source: Energy Information Administration, *Manufacturing Consumption of Energy 1991*, DOE/EIA-0512(91), Washington, DC, 1994, *Manufacturing Energy Consumption Survey: Consumption of Energy, 1988*, DOE/EIA-0512(88), Washington, DC, 1991, and *Manufacturing Energy Consumption Survey: Consumption of Energy, 1985*, DOE/EIA-0512(85), Washington, DC, 1988.

[b]Site energy includes only those Btu available to the establishment. It specifically includes electricity available for the manufacturing establishment (3,412 Btu/kWh).

Table 3. Site Intensity of Offsite-Produced Energy (Structurally Adjusted) in Major Manufacturing Groups, 1985, 1988, and 1991[c]

SIC Code	Major Group	Energy-Intensity Ratios (thousand Btu/constant dollar)			Change in Energy Efficiency (percent)		
		1985	1988 Adjusted	1991 Adjusted	1985-1988	1988-1991	1985-1991
20	Food and Kindred Products	2.53	2.75	2.62	-8.54	4.76	-3.38
21	Tobacco Products	NA	NA	NA	NA	NA	NA
22	Textile Mill Products	4.49	4.50	4.64	-0.20	-3.13	-3.34
23	Apparel and Other Textile Products	NA	NA	NA	NA	NA	NA
24	Lumber and Wood Products	NA	NA	NA	NA	NA	NA
25	Furniture and Fixtures	1.37	1.48	1.39	-8.18	6.04	-1.65
26	**Paper and Allied Products**	**12.27**	**11.08**	**12.99**	**9.66**	**-17.17**	**-5.85**
27	Printing and Publishing	NA	NA	NA	NA	NA	NA
28	Chemicals and Allied Products	11.85	11.40	12.18	3.84	-6.84	-2.75
29	Petroleum and Coal Products	7.63	7.83	8.40	-2.58	-7.25	-10.02
30	Rubber and Misc. Plastic Products	3.04	3.08	2.63	-1.35	14.56	13.41
31	Leather and Leather Products	NA	NA	NA	NA	NA	NA
32	Stone, Clay, and Glass Products	15.52	16.35	17.25	-5.32	-5.53	-11.14
33	Primary Metal Industries	13.84	13.33	13.00	3.68	2.49	6.09
34	Fabricated Metal Products	2.18	2.29	2.21	-4.81	3.44	-1.21
35	Industrial Machinery and Equipment	1.20	1.13	1.08	5.58	3.97	9.34
36	Electronic and Other Electric Equipment	1.15	1.19	1.05	-3.18	11.26	8.44
37	Transportation Equipment	1.04	0.98	1.03	6.25	-5.36	1.23
38	Instruments and Related Products	1.05	1.00	0.97	5.10	2.72	7.69
39	Misc. Manufacturing Industries	1.25	1.21	1.10	3.01	9.71	12.42
	Total	4.35	4.29	4.46	1.38	-3.91	-2.47

NA=Not available. Data are included in higher-level totals.

NOTE: Positive percent change indicates a *decrease* in energy intensity and an *increase* in energy efficiency. Negative percent change indicates an *increase* in energy intensity and a *decrease* in energy efficiency.

Source: Energy Information Administration, *Manufacturing Consumption of Energy 1991*, DOE/EIA-0512(91), Washington, DC, 1994, *Manufacturing Energy Consumption Survey: Consumption of Energy, 1988*, DOE/EIA-0512(88), Washington, DC, 1991, and *Manufacturing Energy Consumption Survey: Consumption of Energy, 1985*, DOE/EIA-0512(85), Washington, DC, 1988.

[c]Site energy includes only those Btu available to the establishment. It specifically includes electricity available for the manufacturing establishment (3,412 Btu/kWh). For 1988 and 1991, intensities are adjusted to reflect the general product mix of the manufacturing sector in 1985.

Table 4. Site Intensity of Total Inputs of Energy (Structurally Adjusted) in Major Manufacturing Groups, 1985, 1988, and 1991[d]

SIC Code	Major Group	Energy-Intensity Ratios (thousand Btu/constant dollar)			Change in Energy Efficiency (percent)		
		1985	1988 Adjusted	1991 Adjusted	1985-1988	1988-1991	1985-1991
20	Food and Kindred Products	2.73	2.88	2.71	-5.55	6.21	1.00
21	Tobacco Products	NA	NA	NA	NA	NA	NA
22	Textile Mill Products	4.50	4.49	4.66	0.20	-3.86	-3.65
23	Apparel and Other Textile Products	NA	NA	NA	NA	NA	NA
24	Lumber and Wood Products	NA	NA	NA	NA	NA	NA
25	Furniture and Fixtures	1.59	1.74	2.04	-9.52	-17.62	-28.82
26	**Paper and Allied Products**	**20.17**	**18.40**	**20.92**	**8.80**	**-13.72**	**-3.71**
27	Printing and Publishing	NA	NA	NA	NA	NA	NA
28	Chemicals and Allied Products	13.16	12.61	13.74	4.16	-8.90	-4.37
29	Petroleum and Coal Products	20.36	22.81	22.21	-12.00	2.61	-9.07
30	Rubber and Misc. Plastic Products	3.05	3.09	2.66	-1.42	14.08	12.86
31	Leather and Leather Products	NA	NA	NA	NA	NA	NA
32	Stone, Clay, and Glass Products	15.84	16.45	17.57	-3.88	-6.81	-10.96
33	Primary Metal Industries	21.54	19.48	18.68	9.56	4.08	13.26
34	Fabricated Metal Products	2.19	2.29	2.21	-4.58	3.61	-0.80
35	Industrial Machinery and Equipment	1.19	1.12	1.08	5.59	3.56	8.96
36	Electronic and Other Electric Equipment	1.15	1.19	1.05	-3.49	11.45	8.36
37	Transportation Equipment	1.03	0.97	1.08	5.40	-11.13	-5.13
38	Instruments and Related Products	1.04	1.00	0.97	3.48	3.00	6.37
39	Misc. Manufacturing Industries	1.31	1.23	1.13	6.76	7.88	14.11
	Total	6.06	5.99	6.16	1.11	-2.80	-1.65

NA=Not available. Data are included in higher-level totals.

NOTE: A positive percent change indicates a *decrease* in energy intensity and an *increase* in energy efficiency. A negative percent change indicates an *increase* in energy intensity and a *decrease* in energy efficiency.

Source: Energy Information Administration, *Manufacturing Consumption of Energy 1991*, DOE/EIA-0512(91), Washington, DC, 1994, *Manufacturing Energy Consumption Survey: Consumption of Energy, 1988*, DOE/EIA-0512(88), Washington, DC, 1991, and *Manufacturing Energy Consumption Survey: Consumption of Energy, 1985*, DOE/EIA-0512(85), Washington, DC, 1988.

[d]Site energy includes only those Btu available to the establishment. It specifically includes electricity available for the manufacturing establishment (3,412 Btu/kWh). For 1988 and 1991, intensities are adjusted to reflect the general product mix of the manufacturing sector in 1985.

ENERGY-EFFICIENCY ANALYSIS

This part contains separate discussions for the Paper and Allied Products (SIC 26) major group and the Paper Mills (SIC 2621) and the Paperboard Mills (SIC 2631) industries. Discussions of SIC 26 contain two charts as well as text descriptions. The first chart presents indices for Offsite-Produced Energy consumption and 1987 constant dollar value of shipments indices for years between 1977 and 1991, illustrating the general relationship between output and one measure of energy consumption. A second chart displays both adjusted and unadjusted energy-intensity ratios for 1985, 1988, and 1991. With 1985 serving as the base year for structural-shift adjustments, adjusted intensities are shown only for 1988 and 1991 end years. Of the 20 major manufacturing groups, five groups are excluded from tabular presentation because data on them are unavailable in earlier MECS publications. Discussions of the SIC 2621 and 2631 industries display the chart showing energy-intensity ratios along with text descriptions.

Because of the SIC system's revision in 1987, discontinuities may occur in the historical data covering the time periods before and after 1987. Where possible, chart estimates for years subsequent to 1987 have been recalculated to conform to the 1987 SIC system. Specifically, all charts showing energy-intensity ratios and percent changes in energy efficiency have been re-estimated under the 1987 SIC system, ensuring the comparability of estimates for 1985, 1988, and 1991. However, charts of consumption and output indices for the 1977-1991 time period use both the OMB's 1972 and 1987 SIC system. For those charts, the 1987 definitions are used from 1987 through 1991, while the 1972 definitions are active for years 1977 through 1986. Because earlier MECS efficiency reports employed the 1972 SIC system definition, direct comparison of energy intensities among these publications is impossible.

This paper relies on external data sources. Analysis of SIC-specific number of employees, value of shipments, and cost of materials is based on data from Table 2 of the 1985, 1988, and 1991 *Annual Survey of Manufactures*.[4] Table 4 from those publications also provides data on cost of purchased fuels and electric energy.

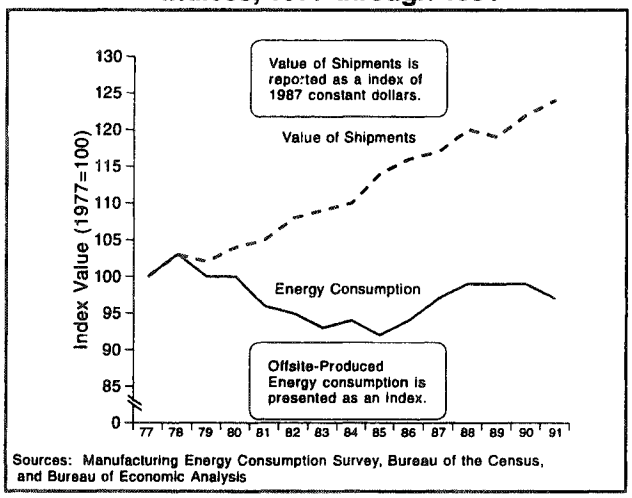
Chart Interpretation - Index Chart

These charts present indices of 15 years (1977-1991) of historical data of constant-dollar value of shipments and Offsite-Produced Energy consumption, using 1977 as the base year (1977 = 100) (Figure 1). Indexing both energy consumption and corresponding constant dollar value of shipments best illustrates the trends in output and consumption. *Taken separately, these two indices track the relative growth rates within the specified major group. Taken together, they reveal trends in energy efficiency.* For example, a steady increase in output, coupled with a decline in energy consumption, represents energy efficiency gains. Likewise, steadily rising energy consumption with a corresponding decline in output illustrates energy efficiency losses.

The vertical axis is truncated in these charts to more clearly identify the relationship between energy consumption and output.

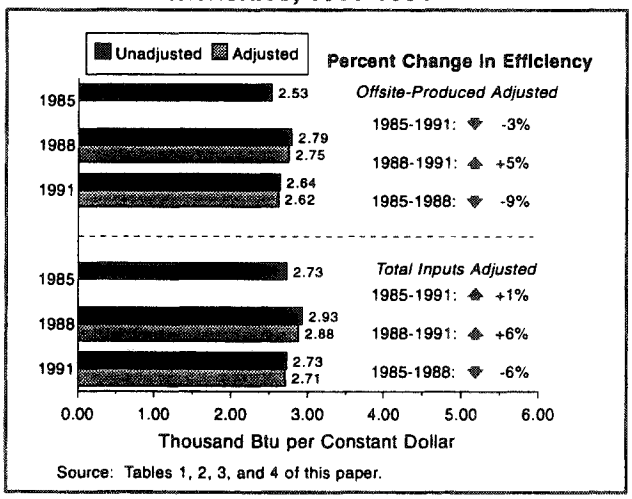
The MECS supplied energy consumption data for 1985, 1988 and 1991. Energy consumption data for the intervening years were calculated using the methodology presented in the EIA publication *Derived Annual Estimates of Manufacturing Energy Consumption 1974-*

Figure 1. Interpretation of Output and Offsite-Produced Energy Consumption Indices, 1977 through 1991



Sources: Manufacturing Energy Consumption Survey, Bureau of the Census, and Bureau of Economic Analysis

Figure 2. Interpretation of Site Energy Intensities, 1985-1991



Source: Tables 1, 2, 3, and 4 of this paper.

1988. The Bureau of Economic Analysis (BEA) provided 1987 constant dollar value of shipments data for the period.

Chart Interpretation - Energy-Intensity Chart

The second figure (Figure 2) presents both the *unadjusted* and *structurally adjusted* energy-intensity ratios, along with the percent change in efficiency, as measured by changes in *adjusted* energy-intensity ratios. Horizontal bars represent those energy-intensity ratios for both Offsite-Produced Energy and Total Inputs of Energy. The actual ratio for the given year is adjacent to the bar.

Given a base year and end year, the percentage changes in efficiency for both Offsite-Produced and Total Inputs of Energy are displayed adjacent to their respective energy-intensity ratios. *Along with the actual percent change, an arrow indicator illustrates the direction of energy efficiency over the specified time period—an upward arrow denotes an improvement in energy efficiency, while a downward arrow denotes a loss in efficiency.*

Both structurally adjusted and unadjusted energy-intensity ratios, if appropriate, are shown.[5] Because 1985 serves as the base year for structural-shift adjustments, energy-intensity ratios adjusted for structural shifts are shown only for 1988 and 1991 end years.

Energy-intensity ratios adjusted for structural shifts can provide relatively clean measures of efficiency change. However, such measures, if they are based only on Offsite-Produced Energy consumption, are incomplete because they ignore the potential impacts of the consumption of Onsite-Produced Energy, such as black liquor, wood chips, petroleum coke, and waste gas. Of the 15.0 quadrillion Btu of Total Inputs of Energy, byproduct consumption accounts for 4.2 quadrillion Btu (28 percent). If Onsite-Produced Energy sources serve as substitutes for Offsite-Produced Energy sources, a change in the relative amounts of the two sources used could mask changes in energy intensity.

Energy efficiency cannot be inferred directly from changes in energy-intensity ratios since structural and behavioral effects are enmeshed in these ratios. While improved energy efficiency does indicate reduced energy intensity, it is also true that a change in energy intensity can result from factors unrelated to energy efficiency. Energy produced onsite and structural shifts in production mix are two of those factors.

PAPER AND ALLIED PRODUCTS, SIC 26

Establishments that produce pulp, paper, or both make up the Paper and Allied Products major group. The group also includes establishments that convert paper and paperboard into products such as paper bags, boxes, or envelopes. This major group also includes establishments that manufacture plastic bags. Five industry groups such as pulp mills and paper mills make up this manufacturing group. These are separated into 17 industries (e.g., corrugated and solid fiber boxes; and plastics, foil, and coated paper bags).

In 1991, the Paper and Allied Products group:

- Employed 620,700 employees (1,900 more than in 1988 and 16,800 more than in 1985).
- Shipped $128.8 billion of goods ($6.3 billion more than in 1988 and $35.4 billion more than in 1985), about 5 percent of total manufacturing value of shipments.
- Spent approximately 8 percent of its total cost of materials for fuels and electrical energy.

Use of Energy

This major group is the third most energy-intensive manufacturing group. In 1991, this group:

- Consumed approximately 14 percent of the Offsite-Produced Energy and about 16 percent of the Total Inputs of Energy for heat, power, and electricity generation in the manufacturing sector.
- Cogenerated more electricity than any other major group.
- Consumed more Offsite-Produced Energy than any other major groups except the Chemicals and Primary Metals major groups.
- Consumed more Total Inputs of Energy than any other major groups except the Chemicals and Petroleum major groups.
- Used byproduct energy sources, such as black liquor, for nearly 50 percent of its total energy requirements for heat, power, and electricity.

Energy Management

The 1991 MECS represents the first-time collection of manufacturers' participation in energy-management activities. To improve energy efficiency, manufacturing establishments participated in various demand-side management (DSM) and other energy-management programs. From 1989 through 1991, their activities and percent of participation, expressed in terms of Total Inputs of Energy used by participating establishments, were as follows: improving the efficiency of steam production (39 percent); improving the efficiency of process heating (32 percent); improving the efficiency of process refrigeration (12 percent); installing or retrofitting motors to achieve better energy efficiency (44 percent); improving the efficiency of facility heating, ventilation, and air conditioning (HVAC) systems (23 percent); and improving the efficiency of facility lighting (33 percent).

General Technologies

To improve energy efficiency, manufacturing establishments in SIC 26 participated in general technologies during 1991. The general technologies and percent of participation, expressed in terms of Total Inputs of Energy used by participating establishments, were as follows: computer control of building environment (17 percent); computer control of processes or major energy-using equipment (82 percent); waste heat recovery (74 percent); and adjustable-speed motors (81 percent).

Industry-Specific Technologies

To improve energy efficiency, manufacturing establishments in SIC 26 participated in industry-specific technologies during 1991. The industry-specific technologies and percent of participation, expressed in terms of Total Inputs of Energy used by participating establishments, were as follows: continuous digesters (50 percent); displacement bleaching process (14 percent); top-wire (hybrid) paper forming (41 percent); extended nip press (23 percent); higher nip pressures (30 percent); extended deliquefaction displacement heating processes (9 percent); falling-film evaporators for black liquor evaporation and concentration (48 percent); vapor recompression evaporation of black liquor (9 percent); waste-heat recovery technologies in lime kilns (23 percent); and improved filtration techniques allowing alternative fuels for lime calcination (9 percent).

Structural Shifts

Since 1985, this major group has shifted noticeably toward more energy-intensive products, as indicated by a structurally adjusted energy-intensity ratio that is much less than the comparable unadjusted ratio. This type of shift occurred in both Offsite-Produced and Total Inputs of Energy (Figure 4).

Impact of 1987 SIC Revision

The 1987 SIC revision moved some industries from the 1977 SIC 2661 to the major group SIC 24 - Lumber and Wood Products. This revision also moved some industries to new three-digit classifications. The reclassification of establishments to a new two-digit SIC major group does not appear to have significantly affected energy efficiency.

Historical Trends in Energy Consumption and Value of Shipments

Between 1977 and 1991, the consumption of offsite-produced energy by the paper and allied products group:

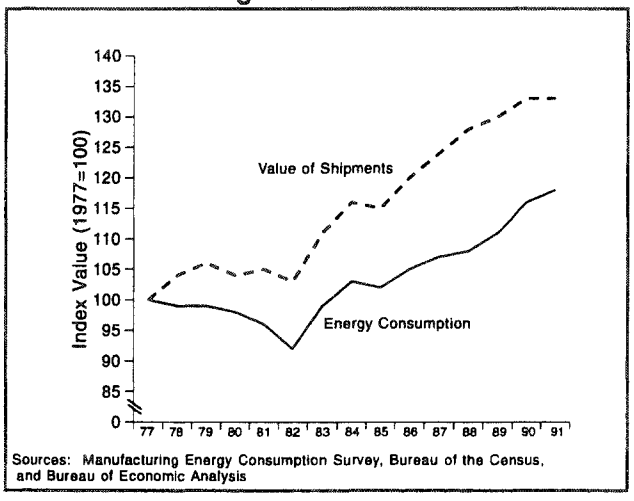
- Declined to a low point in 1982, then increased steadily through 1991.
- Ended 1991 with consumption approximately 18 percent greater than in 1977.

Between 1977 and 1991, the value of shipments (output) for this group:

- Fluctuated through 1982 before beginning a steady increase through 1991.
- Increased approximately 33 percent above the 1977 level.

Energy efficiency increased modestly from 1977

Figure 3. Output and Offsite-Produced Energy Consumption Indices for SIC 26, 1977 Through 1991

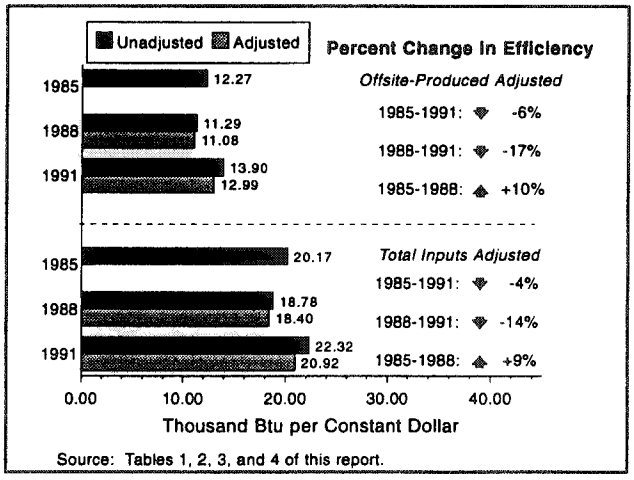


Sources: Manufacturing Energy Consumption Survey, Bureau of the Census, and Bureau of Economic Analysis

through 1985, as evidenced by the two nearly parallel paths that plot consumption and shipment values (Figure 3).

Energy Efficiency (Adjusted), 1985-1991
In the pulp and paper industries, energy efficiency of Offsite-Produced Energy dove by 17 percent from 1988 to 1991, after a 10 percent growth from 1985 to 1988 (Figure 4). In the same way, energy efficiency of Total Inputs of Energy fell by 14 percent from 1988 to 1991, following an advance of 9 percent from 1985 to 1988.

Figure 4. Site Energy Intensities for SIC 26, 1985-1991



PAPER MILLS, SIC 2621
Establishments engaged in the manufacture of paper from wood and other fiber pulp make up this industry. These establishments may also manufacture converted paper products.

In 1991, the Paper Mills industry:

- Employed 130,300 employees (100 less than in 1988 and 1,500 less than in 1985).
- Shipped $33.3 billion of goods ($0.2 billion less than in 1988 and $8.4 billion more than in 1985), approximately 1 percent of total manufacturing value of shipments.
- Spent approximately 15 percent of its total cost of materials for fuels and electrical energy.

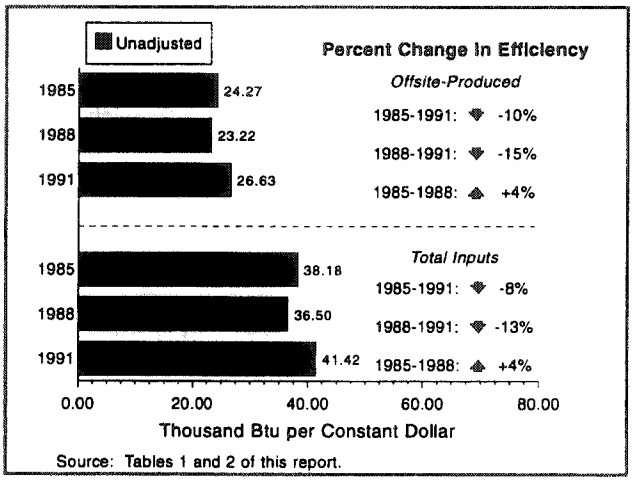
Use of Energy
The Paper Mills industry is the most energy-consuming subsector of the paper industry. In 1991, this industry:

- Consumed approximately 7 percent of the Offsite-Produced Energy and about 8 percent of the Total Inputs of Energy for heat, power, and electricity generation in the manufacturing sector.
- Consumed approximately 50 percent of both the Total Inputs and the Offsite-Produced Energy used by the Paper and Allied Products major group.
- Used Onsite-Produced Energy for 36 percent of its total fuel needs.
- Used byproduct energy sources for approximately 43 percent of its Total Inputs of Energy for heat, power, and electricity generation.
- Consumed energy mainly as boiler fuel, followed by process heating and machine drive.
- Contributed approximately 60 percent of the Paper and Allied Products major group's cogeneration of electricity.

Structural Shifts
Data are not available to determine whether structural shifts affected this industry between 1985 and 1991.

Impact of 1987 SIC Revision
The 1987 SIC revision included in this industry part of the 1977 SIC 2661 - Building Paper and Board Mills industry. This revision also removed the 1977 Pulp and Paper Mills, primarily pulp, which is now part of SIC 2611 - Pulp Mills.

Figure 5. Site Energy Intensities for SIC 2621, 1985-1991



Energy Efficiency (Unadjusted), 1985-1991
In the paper mills industries, energy efficiency of Offsite-Produced Energy dropped by 15 percent from 1988 to 1991, after a climb of 4 percent from 1985 to 1988 (Figure 5). In much the same fashion, energy efficiency of Total Inputs of Energy slid by 13 percent from 1988 to 1991, following an upturn of 4 percent from 1985 to 1988.

PAPERBOARD MILLS, SIC 2631

Establishments primarily engaged in manufacturing paperboard from wood and other fiber pulp make up the Paperboard Mills industry. These establishments also produce paperboard coated on the paperboard machine, and converted paperboard products. Production processes for paperboard mills are essentially the same as for paper mills. The primary production difference is the thickness of the finished product.

In 1991, the Paperboard Mills industry:

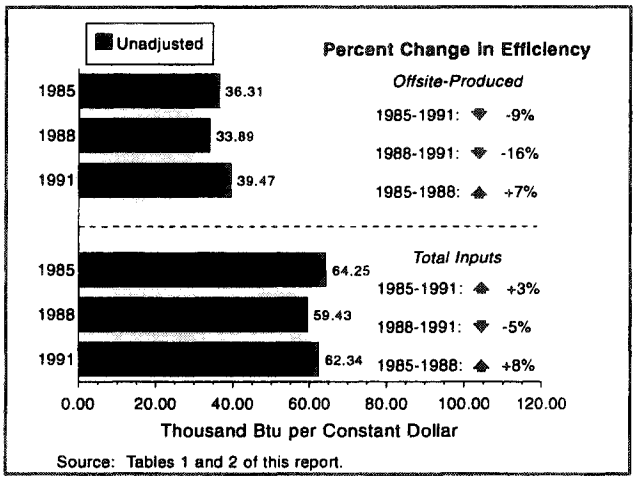
- Employed 50,600 employees (3,000 less than in 1988 and 3,300 less than in 1985).
- Shipped $15.0 billion of goods ($1.1 billion less than in 1988 and $4.5 billion more than in 1985), less than 1 percent of total manufacturing value of shipments.
- Spent approximately 17 percent of its total cost of materials for fuels and electrical energy.

Use of Energy

In 1991, the Paperboard Mills industry:

- Consumed approximately 5 percent of the Offsite-Produced Energy and 6 percent of the Total Inputs of Energy for heat, power, and electricity in the manufacturing sector.
- Consumed approximately 34 percent of the Offsite-Produced Energy consumed in the Paper and Allied Products major group.
- Supplied approximately 56 percent of its Total Inputs of Energy with byproduct energy.
- Contributed approximately 30 percent of the Paper and Allied Products major group's cogeneration of electricity.

Figure 6. Site Energy Intensities for SIC 2631, 1985-1991



Structural Shifts

Data are not available to determine whether structural shifts affected this industry between 1985 and 1991.

Impact of the 1987 SIC Revision

The 1987 SIC revision removed the 1977 Pulp and Paper Mills, primarily pulp, which is now part of SIC 2611 - Pulp Mills.

Energy Efficiency (Unadjusted), 1985-1991

In the paperboard mills industries, energy efficiency of Offsite-Produced Energy suffered a downturn of 16 percent from 1988 to 1991, after a boost of 7 percent from 1985 to 1988 (Figure 6). Also, energy efficiency of Total Inputs of Energy dipped by 5 percent from 1988 to 1991, following a gain of 8 percent from 1985 to 1988.

REFERENCES

1. The opinions and conclusions expressed herein are solely those of the authors and should not be construed as representing the opinions or policy of any agency of the United States Government.
2. Energy Information Administration, *Manufacturing Energy Consumption Survey: Changes in Energy Efficiency, 1980-1985*, DOE/EIA-0516(85), Washington, DC, 1990; Energy Information Administration, *Manufacturing Energy Consumption Survey: Changes in Energy Intensity in the Manufacturing Sector 1980-1988*, DOE/EIA-0552(80-88), Washington, DC, 1991.
3. U.S. Department of Commerce, Bureau of Economic Analysis, National Income and Wealth Division.
4. U.S. Department of Commerce, Bureau of the Census, *Annual Survey of Manufactures.*
5. All MECS surveys are subsampled from the sample for the ASM. Because of the subsampling procedure used for the MECS, it is possible to replicate ASM value of shipments estimates by using MECS establishment weights applied to ASM-reported value of shipments for respondents that were in both surveys. If the MECS-weighted estimates of value of shipments were within 10 percent of the ASM estimate for any given three-digit industry group, that group was judged to be sufficiently reliable to assess structural shift. Those estimates with a difference greater than 10 percent were combined until the 10-percent criterion was met. Counting single three-digit industry groups, 83 groups were judge to be sufficiently reliable.