INDUSTRIAL ENERGY EFFICIENCY: TRENDS, SAVINGS POTENTIAL, AND POLICY OPTIONS

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I. ENERGY USE AND INTENSITY TRENDS

The industrial sector accounts for 36 percent of national energy consumption on a primary basis (i.e., including electrical system losses associated with electricity use)(EIA, 1992). Including indirect emissions from electricity generation as well as direct emissions, the industrial sector is responsible for about 450 million metric tons of carbon emissions annually, about one-third of the U.S. total and about 7 percent of total global carbon emissions (EIA, 1993e). Moreover, the industrial sector has experienced a higher rate of growth in energy demand than the buildings or transportation sectors over the past five years.

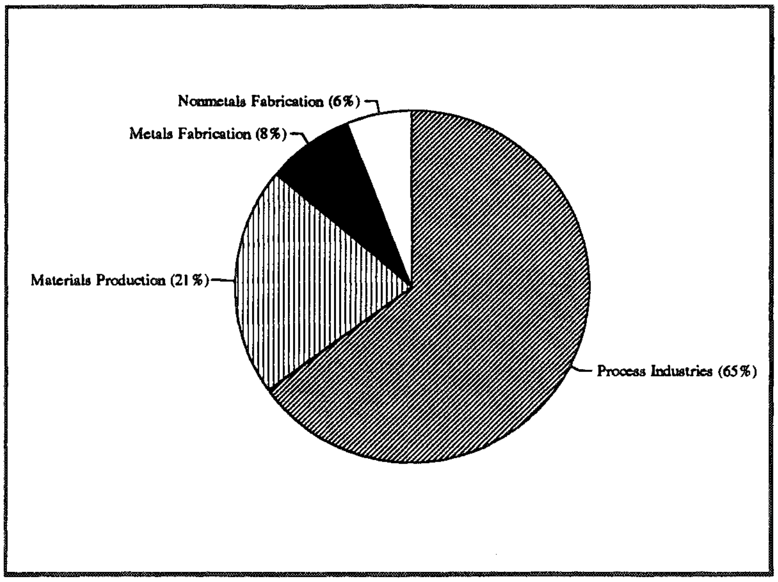

Figure 1 1991 Energy Consumption in Manufacturing Industries (Source: EIA, 1993d).

In 1991, the industrial sector consumed about 22.6 Quads of energy (EIA, 1993c). The industrial sector is further broken down into manufacturing and nonmanufacturing activities. Manufacturing consumes almost 86 percent of sectoral energy. Manufacturing industries include the groupings of process industries, materials production, and materials fabrication. The nonmanufacturing sectors include agriculture, mining and construction (OTA, 1993).

Of the manufacturing industries, process industries are the largest grouping, accounting for 65 percent of manufacturing energy (*Figure 1*). This grouping includes the petroleum refining, chemicals, pulp and paper, food, textiles, and tobacco industry groups. The 3.2 Quads consumed by materials production industries like primary metals, ceramics and glass accounts for over one-fifth of the energy consumed by manufacturing industries, with steel alone accounting for two-thirds of that amount. Metals and nonmetals fabrication account for 8 and 6 percent, respectively, of manufacturing energy consumption (EIA, 1993d).

Petroleum refining and chemicals are the largest energy consuming industries, each accounting for about one-fifth of the total U.S. manufacturing energy consumption (*Figure 2*). In petroleum refining, 62 percent of the energy comes from process by-products and wastes. The chemical industry is the largest consumer of commercial energy sources with over half of its three Quads of site energy coming from natural gas. The pulp and paper industry is the third largest consumer, obtaining about 71 percent of its 2.5 Quads of site energy from process wastes. The primary metals consumes 2.3 Quads of site energy, with steel accounting for 68 percent of this sector's consumption (EIA, 1993d).

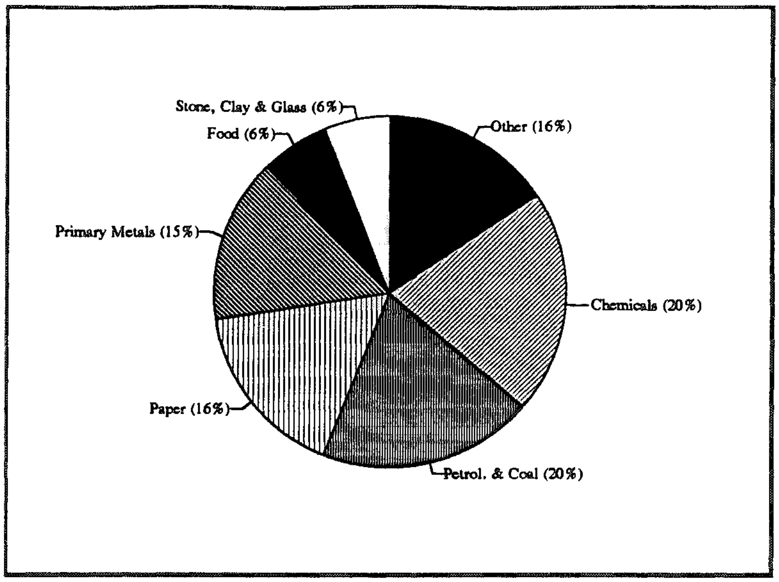

Figure 2 1991 Manufacturing Energy Consumption by Industry Group (Source: EIA, 1993d)

Over one-third of all energy consumed by manufacturing industries come from by-products and waste products of the production process such as waste gas, pulping liquors and wood bark (*Figure 3*). Of these products, two-thirds are consumed in the petroleum refining, and pulp and paper industries. Natural gas is the largest commercial energy source for industry, a third of which is used by the chemical industry. Steel manufacturing accounts for over half the coal and coke consumed by manufacturing industries, with most of the rest consumed by the chemicals, pulp and paper, and cement industries. Electricity is the most ubiquitous energy source, accounting for a low of only 4 percent in petroleum refining but increasing to more than one-third of the total energy consumed in textiles and metals fabrication. In printing, and rubber and plastics products, electricity approaches half of total energy consumption, and in aluminum it exceeds 90 percent (EIA, 1993d).

Manufacturing industries purchased over 55 billion dollars of fuel and electricity in 1991. Electricity accounted for almost two-thirds of these energy purchases even though it represents only 12 percent of industrial energy consumption on a site basis. Electricity purchases exceeded fuel purchases in all industry groups except petroleum refining, and stone, clay and glass (*Figure 4*)(Census, 1992).

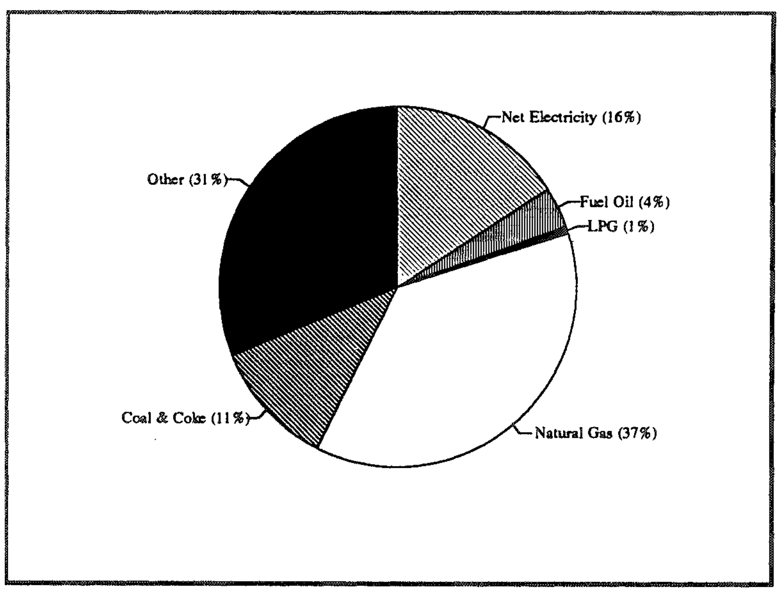

Figure 3 1991 Manufacturing energy Consumption by Fuel Type (Source: EIA, 1993d).

The average expenditure by manufacturing industries for

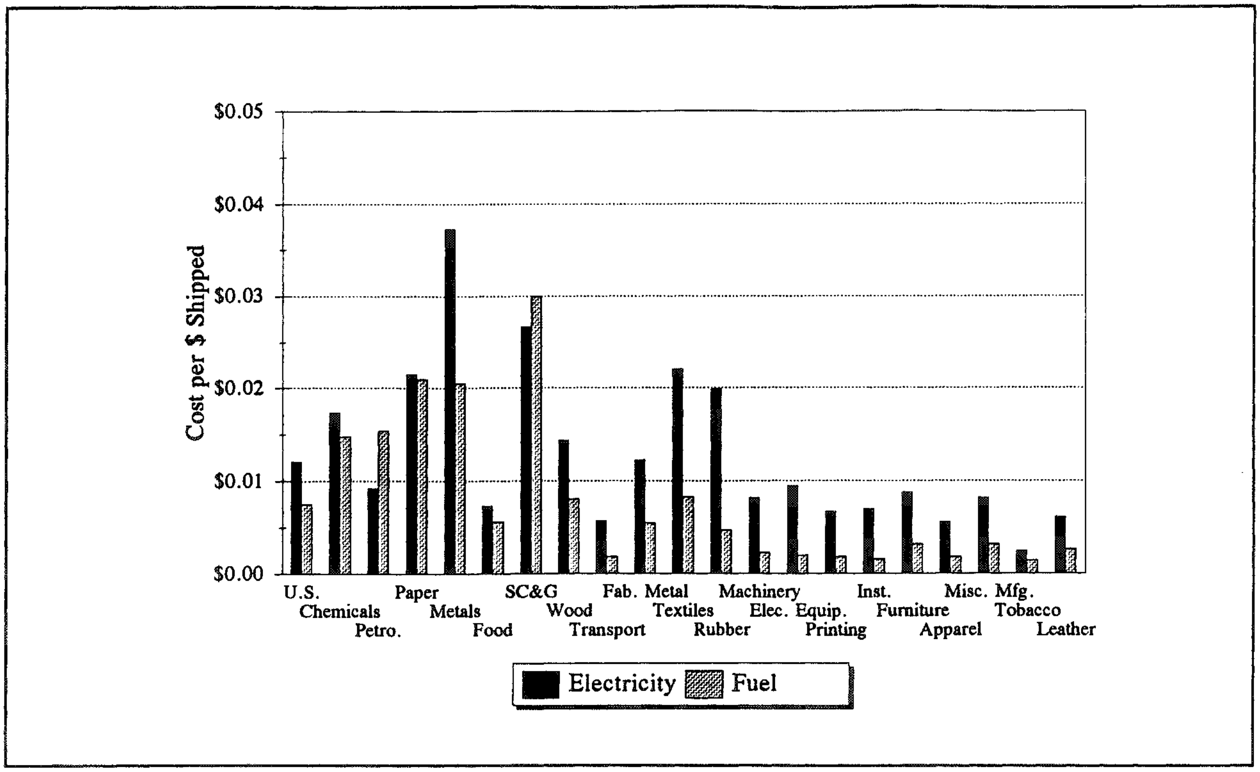

Figure 4 1991 Purchased Energy Costs (Source: Census, 1992)

purchased energy is about 1.9¢ per dollar of value shipped, averaging 1.2¢ for electricity purchases and 0.7¢ for fuels (*Figure 4*). There is significant variation among the industry groups. Most of the fabrication industry groups (e.g., transportation equipment, apparel, printing and furniture) have energy costs of less than 1¢ per value of dollar shipped. In the more energy intensive industry groups (primary metals; pulp and paper; and stone, clay and glass), total energy expenditures exceed 4¢ per dollar of shipment value. Within those industry groups some industries are much more intensive, with energy costs exceeding 20¢ per dollar of shipment value in primary aluminum, industrial gases, alkalies and chlorine production, and portland cement (Census, 1992).

The primary metals, chemicals, paper and pulp, petroleum refining and other basic industries made great strides in reducing their energy intensity during 1973-1985. Considering all manufacturing industries, primary energy consumption per real dollar of industrial output fell 32 percent during this period (Geller, et al., 1991). About 60 percent of this reduction in overall energy intensity was due to improvements in energy efficiency resulting from modernization of manufacturing processes, installation of specific energy efficiency technologies, and so-called housekeeping measures (Schipper, et al., 1990). The other roughly 40 percent of the overall reduction in energy intensity during 1973-85 was due to structural shifts toward less energy-intensive products. In other words, the manufacturing sector as a whole has been shifting away from products such as steel and aluminum, and toward products like electronic equipment.

The manufacturing sector experienced an overall annual rate of energy intensity reduction of over 5 percent per year for the period from 1980 to 1985 (*Figure 5*)(EIA, 1991). A portion of this rapid rate of reduction was due to a serious contraction in some of the large, energy-intensive industries (see examples of raw steel and aluminum production in *Figure 6*)(AISI, 1993 and AA, 1993). The period from 1985 to 1988 saw a slowdown in the overall rate of reduction of manufacturing energy intensity. According to Department of Energy survey data, the overall rate of reduction was only about 1.5 percent per year during 1985-88 (EIA, 1991). Based on preliminary industrial energy consumption data for 1991 (EIA, 1993), ACEEE estimates that the rate of reduction energy of manufacturing energy intensity accelerated to 3.5 percent per year during 1988-91. While this was a significant improvement over the rate of energy intensity improvement during 1985-1988, it still did not match the rate during the early 1980s.

Certain industry groups, notably the chemicals industries, have performed significantly better than the other industries in maintaining energy intensity reductions in recent years (*Figure 5*). But between 1985 and 1992, total industrial energy consumption rose 15 percent (EIA, 1993b), the same percentage increase as U.S. industrial production while manufacturing production (in terms of dollar output) increased 20% for the same period (Census, 1993). The slowdown in industrial energy intensity improvement is due to a number of factors, including the plunge in oil price in 1986, the economic recession that cut investment in new plant and equipment in recent years, and a modest recovery in some of the energy-intensive manufacturing industries such as steel and aluminum production (*Figure 6*) (AISI and AA, 1993).

II. ENERGY EFFICIENCY POTENTIAL

The slowdown in energy intensity improvement recently is **not** due to a lack of technological or economical opportunities. Available energy efficiency measures include process innovation and modernization, better use of waste heat sources, cogeneration systems, waste minimization, increased recycling and use of post-consumer scrap, more efficient motor systems, and better process controls.

Recent studies have estimated an energy conservation potential in the manufacturing sector of between 11 to 37 percent. The U.S. Department of Energy estimated a technical and achievable energy savings potential of 27 and 13 percent by 2010 respectively (Office of Conservation, 1988). Another DOE-sponsored study estimated that industrial energy intensity could be reduced by 24 percent through investments in cost-effective efficiency measures (Carlsmith, et al., 1990). The Office of Technology Assessment (OTA) estimated potential industrial energy savings of between 11 and 37 percent in the year 2015 (OTA, 1991). A study titled *America's Energy Choices*, completed by ACEEE and three other public interest organizations in 1991, determined that if available and cost-effective industrial energy efficiency measures and process improvements were widely implemented, overall industrial energy intensity could fall 1.7-2.5 percent per year over a twenty year period (without

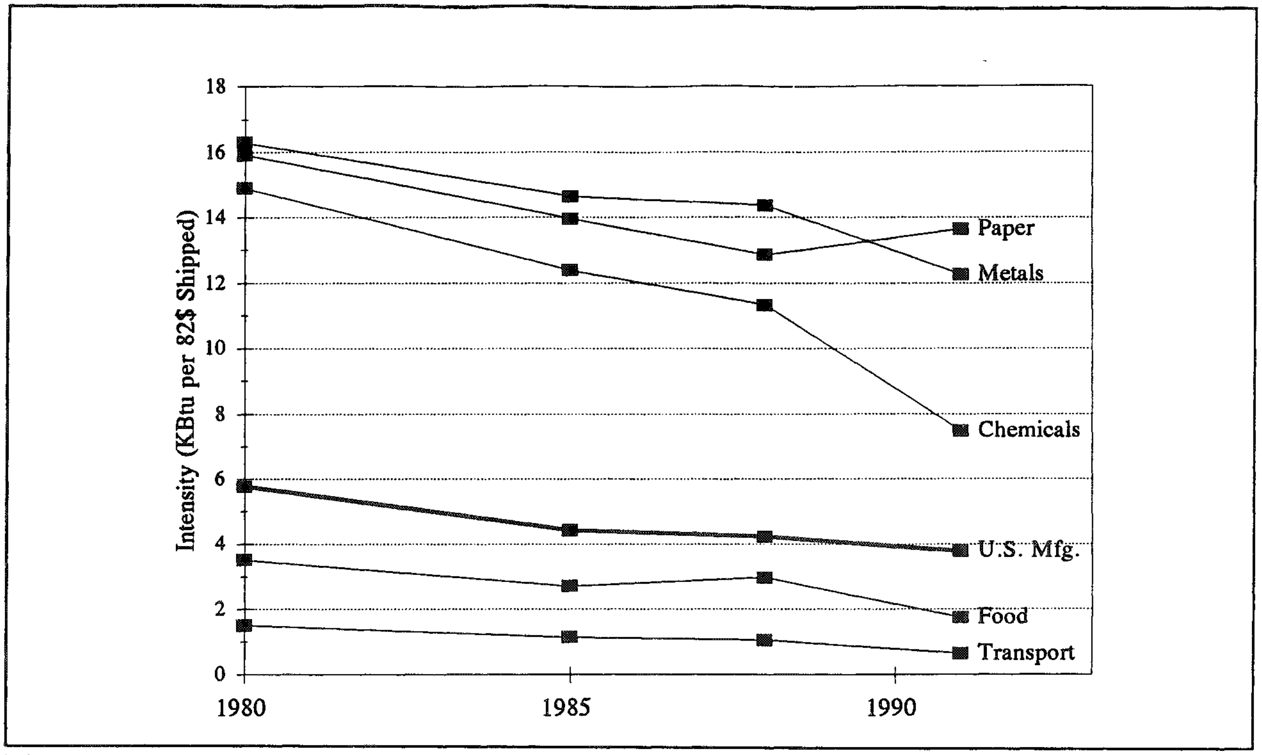

Figure 5 Energy Intensity in U.S. Manufacturing (Derived by ACEEE from EIA, 1991b, EIA, 1993d and Census, 1992)

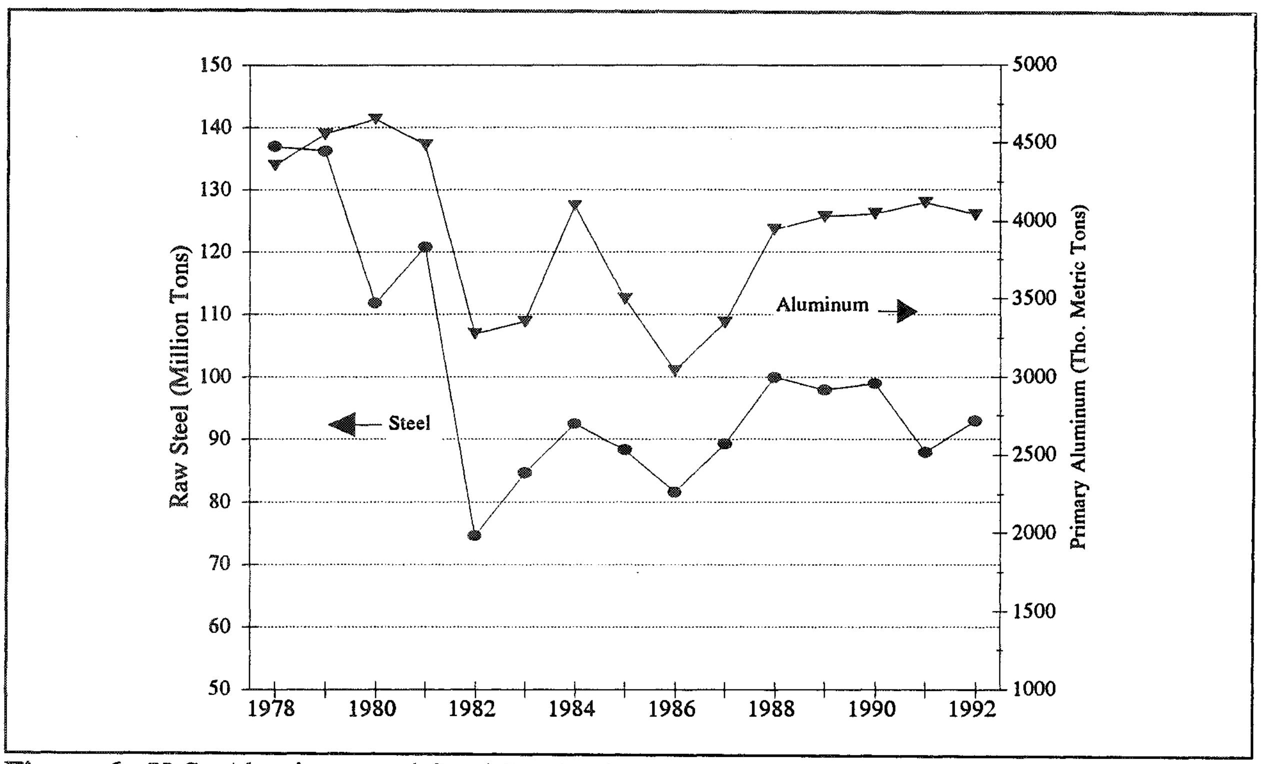

Figure 6 U.S. Aluminum and Steel Production (Source: AISI, 1993 and AA, 1993).

considering structural shifts, which could provide further energy savings). The study estimated that if reductions in energy intensity in this range are achieved, they could lead to an absolute decline in industrial energy use of 10 percent or more, while industrial output and GDP are rising (Alliance to Save energy, et al., 1991).

Several recent studies have estimated the electricity conservation potential in manufacturing. Electric Power Research Institute (EPRI) estimated that by 2000, the application of electricity-saving technologies could save between 24 and 38 percent of industrial electricity use (Faruqui, et. al., 1990). A recent study in British Columbia estimated that the technical and economic potential for electrical energy conservation in industries in the region by 2010 is 34 to 39 percent, respectively (Jaccard, et al., 1993). *America's Energy Choices* estimated the electricity conservation potential to be 24 to 45 percent. Based on a more comprehensive review of the literature, ACEEE estimates an industrial electricity conservation potential in manufacturing to be between 13 and 39 percent of 1991 electricity usage (Elliott, 1994a).

Process and Product Improvements

Industrial modernization can be an important path to greater energy efficiency and greater productivity. While almost all current industrial processes use significantly more energy than the thermodynamic minimum required to do the work, state-of-the art facilities are considerably less energy intensive than typical existing facilities. As a result, an investment in modernization of manufacturing capacity will tend to lead toward greater overall energy efficiency. The reduced industrial energy consumption comes from optimization of existing processes, introduction of process refinements and through technological breakthroughs (Ross and Steinmeyer, 1990). In steel making, for example, overall energy intensity could be reduced by 35-40 percent if all steel mills were as efficient as the current state-of-the-art (Azimi and Lowitt, 1988). Advanced technologies such as direct steel making and direct thin strip casting could reduce energy intensity even further.

Similar large energy savings potentials exist from process improvements in the manufacture of other products as indicated in a recent OTA report on industrial energy efficiency. The average reduction in energy use that could be achieved by full implementation of advanced process technologies over the current technology mix for the seven products in *Table 1* is 35 percent, with energy reductions in both paper and cement of about 50 percent (OTA, 1993).

In petroleum refining, savings can be achieved at many stages of the production process. In the distillation process, various products are separated by heating and condensing the various constituent products. State of the art technologies such as vapor recompression, staged crude preheating, air preheaters, and intermediate reboilers and condensers offer the potential to reduce energy use by 55 percent for this process. In the cracking process, heavier hydrocarbons are heated to break them into more valuable products to meet market needs. A 16 percent savings could be realized from the use of state-of-the-art technologies

Table 1
Opportunities for Efficiency Improvements in the Manufacture of Industrial Products

Industrial Product	Unit Production	Energy Use (MBtu per unit production)		
		Current Avg.[1] (year)	State-of-the-art (2010)	Advanced (2010)
Petroleum	barrel	0.60 (89)	0.40	0.36
Nitrogen & Oxygen	ton of product	3.7 (85)	3.1	2.8
Ethylene	ton of product	58.2 (88)	57.4	52.4
Paper	ton of paper	34.5 (88)	24.6	18.0
Aluminum	ton of aluminum	177.7 (80)	148.4	123.6
Container Glass	ton of product	15.6 (85)	12.1	8.9
Cement	ton of clinker	4.9 (88)	3.5	2.3

[1] represents average energy use for implemented technologies per unit of production for year specified.

Source: OTA, 1993

Table 2
Energy Required to Manufacture Beverage Containers, Including Energy Consumed in Materials Production
(Btu/pound)

Source	Glass	Steel	Plastic	Aluminum
Virgin Materials	6500	35,000	35,000	100,000
Recycled Materials	4500	15,000	15,000	25,000

Source: Steinmeyer, 1992

like fluid coking, mechanical vacuum pumps and hydraulic turbine power recovery. Overall savings from all measures could achieve a savings of as much as 40 percent (OTA, 1993).

The chemicals and allied products industry group produces a diverse group of products ranging from organic and inorganic industrial chemicals to synthetic materials and drugs. Nitrogen and oxygen production is one of the most energy intensive processes. In conventional facilities air is cleaned, liquified and the separated into oxygen and nitrogen by distillation. Improvements to the distillation process can achieve as much as a 24 percent improvement in energy efficiency. The Moltex process, in which oxygen in reacted with molten alkali nitrates and nitrites to produce oxygen, requires only 40 percent as much energy as cryogenic distillation (OTA, 1993).

Paper making requires a complex set of processes to produce a range of different products from tissue to card board. Process refinements or substitutions are possible in each step. In the pulping process, state-of-the-art technologies such as continuous digestors can reduce the energy use by as much as 26 percent. In the chemical recovery step of the kraft and sulfite processes, improved waste heat recovery can reduce energy use by as much as 37 percent from current average practices. Paper making which accounts for over a third of the energy involved in paper production involves preparation of the pulp fibers, forming of the "sheet" and removing the water. Improved water removal can reduce the energy of this production stage by 32 percent and advanced drying techniques, such as impulse drying, can further reduce energy use by as much as 27 percent (OTA, 1993).

Production of portland cement is very energy-intensive. Three-fifths of the energy is consumed in the clinker production where raw materials are burned in a kiln. The use of state-of-the-art technologies including process preheat, use of catalysts, and advanced controls can reduce the energy consumption in this process 26-43 percent (OTA, 1993).

Another opportunity for improved industrial energy efficiency is increasing the recycled content of primary materials or fabricated products. For example, producing a beverage container from recycled materials requires a total of 30 to 75 percent less energy than producing the same product from virgin materials (see *Table* 2). ACEEE estimates that by increasing the recycled content of container glass, aluminum, steel, paper and plastic to targets deemed achievable by 2010, 0.7 1.3 Quads of primary energy could be saved annually. In addition, greenhouse gas emissions would be reduced by 15 23 million metric tons of carbon equivalent. The targeted level of recycled content assumed in this analysis is already being achieved in some operating facilities (Elliott, 1994b).

Electric Motor Systems

Electric motor systems (EMS) represent an excellent opportunity for improving industrial energy efficiency. Approximately two-thirds of all industrial electricity is used by motor systems, which represents 46 percent of the electricity used by all motors nationally. In some process industries, the fraction of electricity consumption by motors can approach 95 percent. EPRI estimates that savings of 28 45 percent are achievable by the year 2000 through the use of energy-savings technologies (Faruqui, et. al., 1990). Many opportunities exist for improving the efficiency of motor systems including:

- improved motor design
- adjustable-speed drives
- optimal motor sizing
- better motor repair practices
- improved motor controls
- electrical system turn-ups
- drive system improvements
- improved efficiency of motor driven equipment
- better maintenance practices

The area of motor design has been the major focus of most efforts to improve motor efficiency to date. An efficiency improvement of 2 to 7 percentage points can be realized by switching from standard to high-efficiency integral horsepower induction motors. This change alone could save on the order of 26 TWh of electricity nationwide (Nadel, et al., 1992). For comparison, the manufacturing sector consumed a total of 694 TWh electricity as of 1991 (EIA, 1993d).

Adjustable speed drives allow the motor to be matched to the process requirements by varying the motor's speed. This ability is particularly important for centrifugal loads such as fans, pumps and compressors whose energy requirements vary as a cube of the speed (Industrial Electrotechnology Laboratory, 1992b). The energy reduction from this technology can be dramatic. For example, by using an ASD to control airflow in hardwood-lumber dry kilns to match the process drying requirements, energy consumption can be reduced by half (Industrial Electrotechnology Laboratory, 1992a). It is estimated that the application of ASDs in industry could save between 22 and 119 TWh annually based on motor use in 1990 (Nadel, 1992).

The motive system includes, in addition to the motor, other components such as pumps, flow control, piping, etc. Significant opportunities can exist for improvements in each component. A program focused only on high efficiency motors and ASDs could miss much of the efficiency improvement potential. Estimates of the potential from motors and ASDs alone range from 15 to 45 percent, while examination of the overall system indicates a savings potential of 28 to 70 percent (Jaccard, et al., 1993). Improving the efficiency of motor-driven equipment such as pumps, fans, compressors and conveyors also offers promise for additional savings. Pumps, fans and compressor account for over 40 percent, and conveyors account for almost 30 percent of the industrial motor load (Resource Dynamics, 1992). ACEEE estimates that minimum efficiency specifications for pumps, fans and compressors, based on currently available technology, could realize an additional 15 TWh of savings by 2010. Even greater savings might be achievable with advanced designs (Nadel, 1994).

In addition to the direct energy savings, improved motor system efficiency would result in reduced losses in electric distribution systems and reduced waste heat from motors, implying lower AC requirements in buildings with mechanical cooling. These savings would provide between 2 and 5 percent additional energy savings. If all the opportunities for savings are combined, as shown in *Table 3*, the total savings potential from industrial motors is between 113 and 291 TWh annually.

Table 3
Saving Potential from Industrial Motors

	National Savings (TWh/yr)	Prorated Industrial Savings (TWh/yr)[a]
Induction motors		
Replacement with high induction motors	59	27
Elimination of past rewind damage	15	7
Correction of motor sizing	8	4
Electrical tune-ups	14-72	6-33
Motor controls	75-298	35-137
DC and synchronous motors	3	1
Drivetrain, lubrications and maintenance (3-7% from all measure on all motors)	34-98	16-45
Indirect Savings		
Reduced distribution loss	24-55	11-25
Reduced AC requirements	12-24	6-11
Total Savings	245-632	113-291

[a] prorates all measure for 46 percent industrial share of total motor energy use.
Source: adapted from S.Nadel et al., 1992.

Lighting

Lighting represents on average 7 percent of the electricity consumption in the manufacturing industries. Though this fraction of end-use is relatively modest, it can represent one of the easiest industrial electricity efficiency opportunities with a cost-effective saving potential of 20-40 percent. Lighting efficiency improvements can be achieved with relatively short paybacks, modest capital expenditures, and are perceived as being less involved with the manufacturing process than other investments. In addition, lighting can account for a fifth to a quarter of electricity consumption in some industry groups such as textiles, printing, tobacco and apparel (Elliott, 1994a).

III. BARRIERS TO GREATER ENERGY EFFICIENCY

In spite of the large energy savings potential in the industrial sector, numerous barriers inhibit industrial energy efficiency improvements. Outside of a few industries, energy is a relatively minor cost of production (*Figure 7*). Purchased energy represents 2 percent of the value of products shipped for all manufacturing industries. This compares with labor at about 9.5 percent and purchased materials at 51 percent. Among the major industry groups, the only group in which energy costs exceed labor costs is petroleum refining. However, total process energy costs for petroleum refining are only about 4.3 percent of the value of the final products. In primary aluminum and industrial gases, energy costs do exceed 20 percent of the value of the final products, but these are the exceptions. Many other industries have energy costs of less than one percent of the value of output (Census, 1992). Thus, given the modest relative cost of energy in most industries, plant and corporate managers tend to be

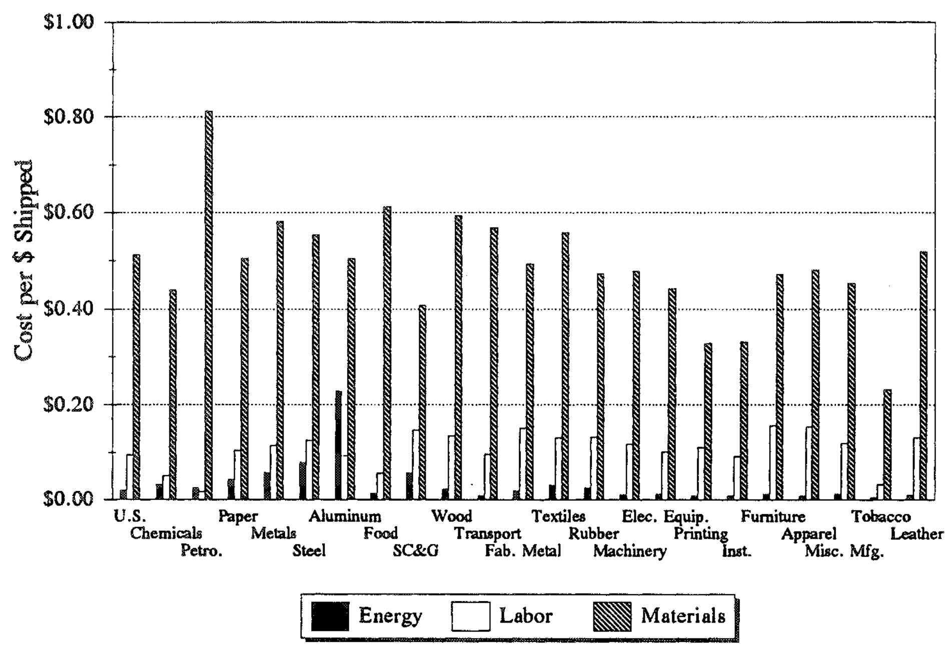

Figure 7 Costs of Manufacturing (Source: Census, 1992).

more concerned about increasing product quality and productivity, cutting materials costs, meeting environmental regulations, and improving labor relations than in reducing energy use.

Low energy prices are another barrier to industrial energy-efficiency improvements. Corrected for inflation, the average energy price paid by industrial customers declined 29% between 1985 and 1991 (EIA 1993c). Market energy prices do not reflect the substantial environmental, national security, and other "externality costs" associated with energy use. Also, low and declining market energy prices limit interest in energy efficiency among businesses, even though many energy-efficiency opportunities remain cost effective.

Many companies view decisions that have an effect on products and output (such as decisions related to new production facilities) differently from decisions that have little or no effect on products or output. Production-related decisions are made at high levels in the corporate bureaucracy and are evaluated against the cost of capital. Decisions with little or no impact on production (e.g., improving the energy efficiency of lighting or motors systems) are often made at the plant level and are subject to "capital rationing". Only a limited amount of capital is available for these marginal improvements which often constrains acceptable payback periods (Ross 1986). In many companies, pure energy efficiency projects must offer a payback of two years or less in order to be implemented (Geller, et al., 1991).

While competition for capital and high hurdle rates are certainly barriers to energy efficiency investments in many industries, some improvements can be realized with little if any capital expenditure. In these cases, competition for the attention and time of management and technical staff may limit the improvements that get implemented. Industry often employs a decision making hierarchy that focuses staff attention first on keeping a plant operating and meeting customer requirements. Next come issues that must be addressed sooner or later, such as compliance with environmental regulations. If plant staff still have time, they might then undertake preventive maintenance. Staff may never get around to considering discretionary issues like energy efficiency improvements (Elliott, 1993).

Lack of time and attention relates to the staff downsizing that has occurred in many companies. During the 1970s, it was common to find an individual or entire department devoted to managing energy use. The decline in energy prices and the financial problems most manufacturing companies experienced during the 1980s eliminated many industrial energy managers. Energy management was handed over to engineering and maintenance staffs, which often do not have the time nor expertise to identify and implement process modifications. Downsizing also has affected corporate management, often leading to a lack of attention to energy performance at the top levels of a company.

Even when an energy efficiency measure provides multiple benefits including increased productivity, reduced pollutant emissions, or improved product quality as well as energy savings, it can take many years for the innovation to fully penetrate potential applications. For example, it took 25 years for the U.S. integrated steel industry to widely adopt the basic oxygen furnace, even though this major process innovation cuts energy use, reduces steelmaking time, and lowers the cost of steelmaking significantly compared to use of the open hearth furnace (Oster 1982). In the case of other less significant innovations, some companies may lack adequate information or fear that adoption could adversely affect operations in some way.

The complexity of the energy decision making process is another barrier. Energy decisions are not made independently, but rather as a part of the operation of a complex organization. Decisions concerning process modifications may have to receive approval at many levels, starting at the plant level and then moving up to the division and corporate level. In many plants, facility operations are managed separately from the process operations. Depending upon the company, these parallel tracks may extend to the corporate level.

Some of the most effective industrial energy efficiency programs have made adjustments in order to survive and thrive within existing corporate decision-making structures. Rather than focus on energy, they have presented projects in terms that management readily relates to, such as productivity and cost effectiveness (Nelson, 1994). At the same time, some effective energy programs have brought about a change in the plant culture. Efficiency should be viewed as doing a good job. Most employees want to do a good job, so what is required is to "empower" them as is shown in the example of the Louisiana Division of Dow Chemical Company (see sidebar) (Nelson, 1994).

While some utility and governmental energy efficiency programs directed toward industrial customers have been successful, it is by no means easy for outside parties to play a useful role in influencing energy decisions or providing technical support to industries. These external parties often lack familiarity with the details of individual plants or the decision making process in particular companies. It might take years to develop, obtain approval, install, and "work the bugs out" of a particular energy efficiency project. It is often difficult for a utility, industrial extension service or state agency to stay involved through all stages of this process.

However when strong partnerships are formed between an outside party and an industrial facility, the benefits can be significant. A striking example is the Breyers ice cream plant in Framingham, Massachusetts. With the technical and financial assistance from Boston Edison and the Massachusetts Division of Energy Resources, the plant implemented $3.5 million of energy efficiency improvements. Energy consumption in the plant was reduced by one-third, cutting the overall energy cost from 7.5¢ to 5¢ per gallon of ice cream. As seen in this example, energy efficiency improvements can significantly affect the competitiveness of industrial plants. Before the project, the plant was slated for closing as part of a Kraft/General Foods corporate cost reduction program. The energy savings were sufficient to not only keep the plant open, but led Kraft to expand the facility and hire additional workers (Massachusetts Energy Efficiency Council, 1992).

Overcoming Barriers to the Industrial Energy-Efficiency Improvement: The Example of the Louisiana Division of the Dow Chemical Company

An inspiring example of how to realize industrial energy efficiency improvements through corporate cultural change is told by Ken Nelson, recently retired from the Dow Chemical Company. The Louisiana Division began an annual Energy Contest in 1981 conducted by an energy committee organized by Nelson. Plant employees were encouraged to make energy efficiency suggestions with a capital cost of less than $200,000 and a return on investment (ROI) of 100 percent (about a one year payback). In the first year, twenty seven projects passed a review with a capital cost of $1.7 million and an average ROI of 173 percent. Over the next years the number and savings of the proposed projects increased. In 1993, 140 projects costing $9.1 million were implemented and provided an annual cost savings of $28.4 million (see table).

Dollar Summary of Winning Contest Projects (< $2 million) having ROIs Above the ROI Cut-off

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Cost, $Million	1.7	2.2	4.0	7.1	7.1	10.6	9.3	7.5	13.1	8.6	6.4	9.1
Savings, $Mill/yr:												
Fuel Gas	2,970	7,650	6,903	7,533	7,136	5,530	4,171	3,050	5,113	2,109	5,167	4,586
Yield & Cap.	83	-63	1,506	2,498	798	3,747	13,368	32,735	8,656	17,909	11,645	20,311
Maintenance	10	45	-59	187	357	2206	583	1,121	1,675	2,358	2,947	2,756
Miscellaneous	0	0	0	0	0	19	-98	154	2,130	5,270	518	788
Total Annual Savings, $Mill./yr	3,063	7,632	8,350	10,218	8,291	11,502	18,024	37,060	17,575	27,647	20,277	28,440

Most of the proposed projects were process improvements which yielded increased output worth even more than the energy cost reductions. The Dow Energy Committee that ran the program circumvented any threats to management, the only exerting influence, not attempting to control staff and money. The program empowered" plant engineers to make their plants more efficient. The contest offered no cash rewards, since setting up a parallel reward system could have conflicted with the existing system recognized as part of employees normal job review.

Nelson remarks that he never received full support from management, but rather their tolerance. The program persisted in part because it was isolated from changes in top management. It was allowed to survive because it showed profitability, which made top management look good.

Source: Nelson, 1994

IV. STRATEGIES FOR INCREASING INDUSTRIAL ENERGY EFFICIENCY

To accelerate industrial energy efficiency improvements and enhance the competitiveness of American industry, we believe a combination of strategies should be pursued. Since energy use per se is not a priority for companies, these strategies should, in general, target the issues that industries do care about competitiveness, improved productivity, better product, quality, and/or reduction in pollutant emissions and environmental compliance costs. Fortunately, greater energy efficiency can provide multiple benefits such as greater productivity, lower maintenance costs, lower emissions, and enhanced competitiveness as shown in the Dow and Breyers examples.

Research, Development and Demonstration

The U.S. Department of Energy, Office of Industrial Technology has been developing new industrial technologies that are intended to reduce industrial energy use while providing other benefits. Some of these technologies are beginning to be adopted on a significant scale. These technologies resulted in at least 80 trillion Btu savings for 1992 and cumulative savings of 419 trillion Btu. As an example, results for eight of the most successful technologies are presented in *Table 4*. The adoption of OIT developed technologies has also generated 8,300 man-years of additional employment, increased capital productivity $540 million dollars and has meant that seven billion tons of carbon dioxide were not emitted into the environment (Office of Industrial Technologies, 1992).

The Office of Industrial Technology spent slightly less than $90 million on RD&D in FY94, up from a total of about $30 million as of FY89. Major areas of emphasis include industrial waste minimization and reuse, materials processing, and advanced materials development. The OIT program should continue to grow in key areas such as electric drives, sensors and controls, and cogeneration systems (Anon. 1993). In addition, OIT should expand its promotion and deployment efforts so that there is greater adoption of new energy efficiency measures.

Industrial Equipment

Motors represent the largest single class of industrial equipment. The Energy Policy Act of 1992 (EPACT) set minimum efficiency standards for poly-phase, integral horsepower motors (U.S Congress, 1992). These standards are projected to reduce electricity use in 2010 by 8 TWh (Geller & Nadel 1992). ACEEE has estimated that an additional 17 TWh could be saved by 2010 from minimum efficiency standards for fractional horsepower and single-phase motors (Nadel, 1994). EPACT gives DOE authority for setting such standards.

Educational initiatives, including dissemination of the *Motor Master* motor selection database, have raised awareness concerning energy-efficient motors among motor users (WSEO, 1993). Heightened consumer awareness has not only resulted in better consumer decisions, but has also provided motor manufacturers with an incentive to market premium efficiency motors (GE, 1993).

Under President Clinton's *Climate Change Action Plan*, DOE is creating a *Motor Challenge* program which will first demonstrate energy-efficient electric motor systems in 25 companies. DOE will then use these demonstrations in a marketing effort to stimulate

Table 4
Energy Impacts of Successful Technologies Developed in part with Federal Funding by the U.S. Department of Energy

Technology	Total Federal Cost Unit	Units Operating	1992 Energy Savings (Quads/yr)	Cumulative Energy Savings (Quads/yr.)	Increased as of 1991 Employment (Man-Years)
Computer Controlled Oven	458	15	0.0026	0.0197	44
High-E Welder	444	39,995	0.0024	0.0080	(76)
Cement Classifier	553	46	0.0012	0.0070	267
High Temperature Recuperator	2,580	633	0.0012	0.0189	23
Hyperfiltration - Food	386	10	0.0007	0.0019	433
Catalytic Distillation	1,467	9	0.0006	0.0024	167
Slot Forge Furnace	2,436	27	0.0003	0.0029	57
Hyperfiltration - Textiles	636	5	0.0002	0.0005	161
Reverse Brayton Cycle Solvent Recovery	5,753	2	0.0001	0.0005	48
Solvent Recovery from Effluent Streams	487	6	0.0001	0.0001	61

Source: OIT, 1992

broader adoption of energy-efficient electric motor systems (Clinton and Gore, 1993). ACEEE recommends that the marketing phase of this program begin immediately drawing upon the large body of experience with energy-efficient electric motor systems that already exists. The program should recognize companies who have already demonstrated efficient, motor-management practices or implement these practices outside of the demonstrations. In addition, DOE should work with the utility industry to transfer successful DSM program approaches for electric motor systems to utilities throughout the country.

Opportunities exist for similar initiatives with industrial motor-driven equipment. As mentioned earlier pumps, fans, compressors and conveyors account for over 70 percent of motor load (Resource Dynamics, 1992. Policy and program initiatives that could lead to efficiency improvements in these products include:

- development and/or refinement of test procedures,
- collection and dissemination of equipment performance data,
- incentive programs such as utility financing and rebate programs, and educational programs to raise consumer awareness,
- development and implementation of minimum efficiency standards

Reliable end-use and technical information on these types of equipment is not readily available. Several organizations including the Coalition for Energy Efficiency and DOE have discussed working in these areas. DOE should take a leadership role in developing initiatives for industrial motor-driven equipment. These activities should be coordinated with electric utilities and manufacturers.

An opportunity also exists to encourage manufacturers to provide more efficient motor-driven equipment in the marketplace. The Golden Carrot initiative of Climate Change Action Plan mandates the establishment of a program to promote improved efficiency among motor-driven industrial equipment (Clinton and Gore, 1993). DOE should coordinate this program with state governments and electric utilities who are in a position to create a market for this equipment by specifying it in incentive programs.

Technical Assistance

Expanding technical assistance to companies, particularly to small- and medium-size industries, would be one way for the Federal government, states, and utilities to increase industrial energy efficiency. It would be useful to scale up two successful but relatively modest programs already underway at DOE/OIT: the *Energy Analysis and Diagnostic Centers* (EADC) program and the *National Industrial Competitiveness through Efficiency: Energy, Environment, Economics* ($NICE^3$) program. OIT will be expanding both of these programs in FY94 and further growth is called for in the Climate Change Action Plan (Clinton and Gore, 1993). DOE should also consider collaborating with EPRI in its *Partnership for Industrial Competitiveness* program (Smith, 1993).

Since the EADC Program began in 1976, faculty and students at participating universities have conducted over 4,100 audits of small and medium-size manufacturing plants. DOE estimates that 50 percent of the recommendations have been implemented with an energy savings of over 7.3 trillion Btu as of FY92. Implemented energy efficiency measures have saved companies approximately $ 438 million annually with DOE program costs of $ 26.7 million (Glaser, 1994). *Figure 9* presents the dollar savings by industry for the most recent reporting period, 1989-90. Industry wide, 70 percent of the savings came from manufacturing processes with the remainder from HVAC and housekeeping measures (Office of Industrial Technologies, 1992).

In addition to direct energy savings, the EADC program provides an important indirect benefit hands-on training of young industrial engineers in energy efficiency. A recent DOE roundtable on efficient electric motor systems for industry identified the lack of expertise in Electric Motor Systems as a major barrier to implementation (OEDP and OIT, 1993). In FY94, DOE expects that 125 senior and graduate engineering students will receive training in conducting industrial energy audits. However, these are only a small fraction of the industrial engineers that graduate each year. To complement these efforts, DOE should co-fund curriculum development and promote better integration of energy efficiency concepts and experiences into industrial engineering schools. Some electric utilities have already started programs along these lines. Virginia Power, for example, has begun a program that supports new undergraduate courses and graduate research on thermal-energy storage at several universities including Virginia Tech, N.C. State University and Old Dominion University (Stephenson, 1992).

Utilities and other government agencies have also undertaken technology assistance efforts with similar goals to the EADC program. Notable are the National Institute for Standards and Technology's Manufacturing Technology Centers program, and the system of centers established by the EPRI. Several utilities have also established technology centers for their industrial customers (AEC, 1992). While energy is not the exclusive focus of most of these centers, energy plays an important role in addressing the primary goals of improving industrial productivity and product quality. Unfortunately, there is little coordination among these centers which can lead to confusion in the industrial community and duplication of efforts. The Climate Change Action Plan proposes to improve coordination by having DOE and EPA fund "one-stop-shops" at the state or regional level that would contact companies and direct them to the most appropriate source of information or technical assistance (Clinton and Gore, 1993).

EPACT contains a few technical assistance provisions addressing industrial energy efficiency. Section 131 authorizes grants to industry associations for programs to promote industrial energy efficiency improvement (U.S. Congress, 1992). Section 132 authorizes grants to states for industrial energy efficiency programs, to be conducted in conjunction with utility programs. In FY94, DOE received only about $700,000 for planning of the Section 131 and 132 grants programs. We urge the Congress to provide greater funding for these programs in FY95 and beyond. Apart from R&D sections of EPACT, these are the main provisions that directly address industrial energy use. They are structured as partnerships between the Federal government and other key stakeholders, and they should be given a chance to work.

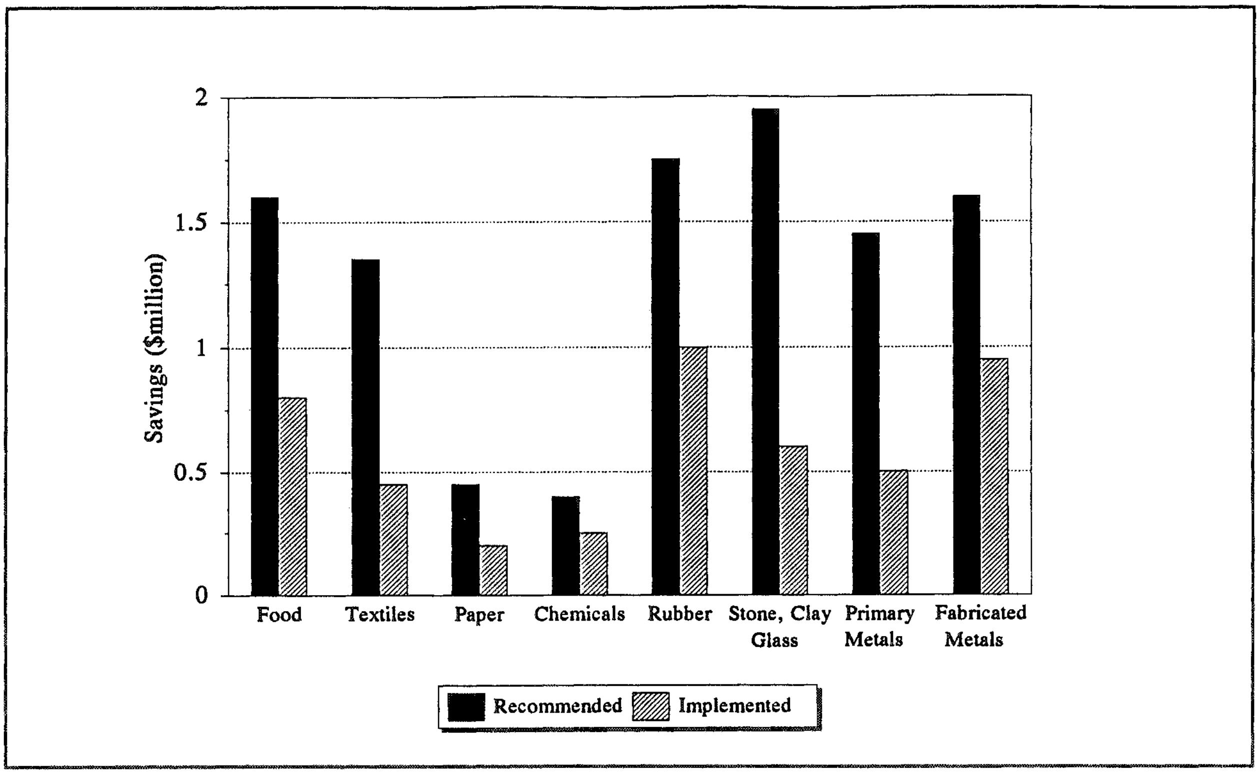

Figure 8 EADC Program Results 1989-1990 (source OIT, 1992).

Utility Programs

Some electric and gas utilities have been offering demand-side management (DSM) programs to industrial customers for several years. According to a comprehensive survey and review of these programs, many industrial DSM programs have had limited impact because they are not well designed and do not focus on industrial customer needs. However, some programs have been successful (e.g., providing energy savings six times that of the average program) because they understand and address the broad concerns of industrial customers. The successful programs were cost effective to the sponsoring utility, with average costs of only 1.4 cents per kWh saved. Several of the most successful programs are described in an accompanying sidebar. In addition to focusing on industrial needs and concerns, the successful programs tend to involve thorough marketing (often relying on regular personal contacts with customers), flexible program design (often featuring both prescriptive and custom design options), substantial financial incentives, and comprehensive technical assistance (Jordan and Nadel, 1993).

Given the large, cost-effective savings potential available in the industrial sector, utilities should expand and improve their industrial DSM programs learning from the experiences gained to date in this area. Moreover, better analysis and verification of the impacts of industrial DSM programs is needed. DOE should continue to support these efforts by

Puget Power's Industrial Conservation Program

This program, in effect since 1981, is open to all industrial customers, though the top 100 industrial customers were initially targeted. Utility staff work with program participants and consultants though the entire process from opportunity identification, through design and installation to savings verification.

The program divides measure into process, HVAC and lighting. Eighty percent of the measures implemented are processes with pumping, motor/ASD and air-compressor related measures the most common. The program has achieved a 5 percent cumulative participation rate with total electric savings of 2.0 percent of industrial electricity sales. The levelized cost of the program in 1991 was 2.6¢/kWh saved.

The utility attributes the program success to integrating the program into utilities energy services, using contractors with expertise in the participating industries, and targeting process-related improvements.

Wisconsin Electric's Smart Money for Business Program

This six year old program offers zero-to-low interest loans or cash rebates to commercial and industrial customers for installing qualifying energy-efficiency measures. Between 20 and 50 percent of project costs are typically covered with the utility paying up to 50 percent of the cost of an audit. Utility field engineers promote the program to plant level personnel while account executives market to industrial vice presidents. In the first five years, almost half of the industrial customers have received loans or rebates through the program with more than half of the industrial savings coming from lighting measures and 30 percent from process modifications. The program manager indicated that lighting and HVAC measures have allowed industrial customers to gain trust in the program before moving to process measures. The program has achieved cumulative savings of 2.5 percent of industrial electricity sales with a levelized cost of 2.1¢/kWh saved.

Southern California Gas' Industrial Equipment Replacement/Heat Recovery Program

Sine 1990, this program has offered incentives to industrial customers to install high-efficiency boilers, burners, economizers and recuperators. The program achieved a 2 percent participation rate and savings of 0.2 percent of 1991 industrial gas sales with a levelized utility cost of 4¢/therm saved. According to the utility, some of the measures implemented help participants meet air quality regulations.

Niagara Mohawk's C&I Motors and Drives Program

This program, begun in 1991, offers fixed incentives for installation of energy-efficient motors and adjustable speed drives. The program generally pays 50 to 75 percent of ASD installation costs. The program works with equipment vendors and assists them with marketing at industrial shows. First-year savings were 0.1 percent of industrial electric sales with a participation rate of 3 percent and a levelized utility cost of 1.5¢/kWh saved.

Source: Jordan and Nadel, 1993.

collecting and disseminating information on the most successful programs and by working to improve evaluation techniques and practices.

Industrial Energy-Efficiency Targets

EPACT directs DOE to evaluate the effectiveness of voluntary energy-efficiency improvement targets for different industrial sectors, and report back to the Congress with its findings. Voluntary energy efficiency targets, along with an annual energy reporting program,were established by the Congress in 1976, but were dropped in the mid-1980s. These targets were established for the ten most energy-consuming industry groups based on a percentage reduction in energy consumption per unit of production relative to 1972 performance. By 1979, five of these industry groups had already met or exceeded their targets (Office of Industrial Programs, 1980). In 1981, all except the fabricated metals product industry group had met or exceeded the targets (Office of Industrial Programs, 1983), and by 1985 all groups had exceeded their targets, many by a factor greater than two (Office of Industrial Programs, 1987). *Table 5* shows the actual performance of the selected industries compared to their 1980 targets for the period 1979-85.

Reinstating energy efficiency improvement targets, which could be set by DOE as voluntary targets, would be useful. DOE stated in a report on the former program, "The Department of Energy concludes that the energy efficiency improvement program has had a positive effect in raising awareness and participation in energy management and conservation

Table 5
1976 Federal
Industrial Energy-Intensity Reduction Targets[1] and Actual Performance.

SIC	Industry Group	1980 Target	1979 Actual	1981 Actual	1982 Actual	1985 Actual
20	Foods	12 %	15.3 %	21.7 %	25.7 %	30.7 %
22	Textiles	22 %	17.7 %	18.6 %	16.5 %	28.5 %
26	Pulp & Paper	20 %	16.9 %	23.3 %	26.4 %	45.7 %
28	Chemicals	14 %	22.1 %	23.7 %	24.8 %	35.4 %
29	Petroleum Refining	20 %	14.7 %	20.6 %	22.6 %	28 %
32	Stone, Clay & Glass	16 %	12.9 %	20.5 %	25.4 %	29 %
33	Primary Metals	9 %	7.8 %	14.3 %	11.1 %	23.9 %
34	Metals Fabrication	24 %	21.5 %	22.7 %	20.4 %	30.5 %
35	Industrial Machinery	15 %	24.7 %	29.2 %	28.7 %	18.1 %
37	Transportation Equipment	16 %	23.4 %	32.3 %	35.3 %	35.8 %

[1] Percent improvement in energy intensity relative to performance in 1972.
Sources: Office of Industrial Programs 1980, 1983 and 1987.

by industrial corporations" (Office of Industrial Programs, 1980). ACEEE recommends that DOE establish two complementary types of voluntary energy reduction targets: 1) targets for industrial sectors (similar to the targets from the 1970s), and 2) targets set by companies for their own facilities. Regarding sectoral targets, they should be set by DOE with extensive input from industry, trade associations and other interested parties. The targets should be based on analyses of the technical and economic potential for efficiency improvement and process innovation, as well as an assessment of the achievable rate of technology implementation. ACEEE also suggests that both short- and long-term targets (2000 and 2010) be set, and that these targets should be revisited periodically, say every five years. In order to judge progress toward achieving new voluntary targets, the existing Energy Information Administration (EIA) *Manufacturing Energy Consumption Survey* can be used as the yardstick. This survey will be conducted biennially beginning in 1993 (Geller, 1994). New targets should be complemented by programs to promote their achievement, including technical assistance efforts, financial incentives, and voluntary programs along the lines described in other sections.

Financial Incentives

The overall business and financial climate will affect the willingness of industries to invest in new equipment and modernize their production facilities, which in turn will affect energy intensities. While factors such as the rate of economic growth, cost of capital, and tax codes are beyond scope of energy policy, they are nonetheless critical to energy efficiency efforts in the industrial sector. Given the magnitude of industrial energy use and its link to other critical issues such as competitiveness, productivity, and carbon dioxide emissions, the Federal government should consider offering direct financial incentives such as loan guarantees, interest rate buy-downs or tax credits for industrial process improvements or retrofits that cut energy intensity and provide other benefits.

The Federal government provided a 10 percent tax credit for investments in specified industrial energy efficiency and recycling equipment during 1978-85. It appears that these tax credits had little impact on corporate investment decisions mainly because they were marginal in magnitude (ASE 1983; OTA 1993). If tax credits are tried again, the size of the credit should be significantly increased (i.e., the tax credit should be on the order of 50 percent) and industries should be given greater flexibility concerning eligible measures. We suggest covering any technology or process modification that reduces energy intensity, using revenues from a broad-based energy or carbon tax to pay for such an incentive program. One possibility would be to focus the incentive on incremental investment, say by excluding investment below a specified percentage of a company's revenues, in order to limit the cost to the Federal government and maximize the impact. The total tax credit a company receives could be capped at its energy or carbon tax liability.

It may be desirable to target financial incentives on small to medium-size companies. Using energy tax revenues or other funding sources, a new Federal energy productivity fund could be established for such companies. The fund could be used to reduce the effective interest rate on private capital borrowed for projects that reduce energy intensity, prevent pollution, and enhance competitiveness. Smaller industries could also use the fund for collateral to secure private loans where necessary. This type of financial incentive program would complement the demonstration, promotion, and technical assistance programs offered by the Federal government, EPRI, and other organizations.

A financial incentive program along these lines could be implemented through state energy agencies. Several states including Illinois, New York, Nebraska, and Tennessee have established their own low-interest loan programs for energy efficiency projects that include small to medium-size industries. Four state programs are profiled in the accompanying side bar. These state programs range from simple loans funds administered by state energy offices, to programs involving commercial lenders. These latter programs include interest rate subsidies, loan repurchase agreements and loan guarantees. By working with financial institutions, the states can leverage their investment (Bartsch and De Vaul, 1992). Federal funds also could be used to expand the loan pool in these state programs, which in some cases is relatively modest.

Tennessee Small Business Energy Loan Program

Tennessee business with fewer than 500 employees and gross sales of less than $3.5 million are eligible for 5 percent loans up to $500,000 to install and incorporate energy efficiency measures in existing facilities. The state has earmarked $5 million to establish this program. The state energy Division reviews and evaluates loan applications.

Oklahoma Energy Loan Interest Program

The Oklahoma program subsidizes loans from private lenders for energy savings improvements in existing facilities. The state has provided $1.5 million to the program which is a joint effort between the Oklahoma Department of Commerce and the Community Bankers Association of Oklahoma. The program provides small businesses a 6 percent reduction on the loan interest rate up to a $30,000 subsidy.

New York Energy Investment Loan Program

This program was established with one-time funding of $27 million by the state of New York. The program subsidizes commercial loans for energy-conservation improvements up to $500,000. On-site power-production projects can receive subsidized loans up to $1 million.

To be eligible, the borrower must meet credit requirements and fall into one of the following categories: have less than 500 employees; gross less than $10 million; be in agribusiness; or own multi-family housing. Two interest rate options exist, 2.5 percent or loans of less than five years and 5.0 percent for loans of five to ten years, as of 1992.

In addition, loan guarantees are available on a first-come, first-serve basis for up to 75 percent of the loan principal. By mid-1992, more than 700 applicants had received loans under this program. Annual energy savings of $5.5 million are expected for the initial $10.6 million of subsidies.

Source: Bartsch and De Vaul, 1992.

Voluntary Programs

Voluntary commitments and recognition, modeled on the successful "Green Lights" program sponsored by the EPA, could be another component of a comprehensive strategy for promoting industrial energy efficiency and productivity improvements. DOE (or another sponsor) could encourage a corporate commitment to implementing all energy efficiency measures and process modifications that offer a rate of return above a certain threshold. For industries, a rate of return equal to or greater than "prime plus 5 to 10 percent" would be reasonable, roughly equivalent to industry's cost of capital. Since industries often require a rate of return of 50 percent or more before they will otherwise implement energy efficiency projects, many more projects would be pursued if the threshold drops to around 10-15 percent. Industries should also pledge to provide the capital, the manpower, and the technical resources necessary to get the job done. DOE could provide technical assistance to companies that make this voluntary pledge if they request it, as well as recognition of "green companies." In addition, it might be useful to have industry associations cosponsor a program along these lines.

The 3M Corporation, for example, has already pledged to implement energy management projects that provide a rate of return of 15 percent or more. This company, which has reduced its energy intensity by over 50 percent during the past 20 years, recognizes the value of energy efficiency for cutting pollutant emissions and improving the bottom-line. It has set a corporate goal of further reducing energy use per unit of product and per square foot of building space by 20 percent between 1990 and 1995 (3M, 1987). If 3M can do it, so can other corporations.

The *Climate-Wise Companies* program announced in the Climate Change Action Plan, provides the framework for moving forward with a program along these lines (Clinton and Gore, 1993). The details of the Climate-Wise program were still being developed by DOE and EPA in early 1994, but the program is aimed at encouraging companies to set voluntary goals for greenhouse gas emissions and recognizing companies who make significant emissions reductions. We recommend that the program focus on energy-intensive industrial sectors and recognize strong commitments as well as top-performing companies. Companies that surpass more modest thresholds (such as a 10% or greater reduction in greenhouse gas emissions relative to a baseline period, normalized for changes in output) could also be recognized.

CONCLUSION

There is large potential to increase energy efficiency in the industrial sector, but a variety of barriers inhibit widespread implementation of cost-effective efficiency measures. The barriers include availability of information, staff and capital, and a lack of a corporate culture that encourages energy efficiency. In addition to adopting macroeconomic policies that will stimulate investment in new equipment and process modernization, Federal policymakers can encourage energy efficiency improvements in the industrial sector by:

1) expanding research, development and demonstration, and technical assistance programs,
2) encouraging more extensive and more effective utility DSM programs for industrial customers,
3) establishing voluntary energy efficiency targets for different industrial sectors,
4) promoting energy-efficiency improvements in electric motor systems,
5) adopting minimum efficiency standards on specific industrial products,
6) encouraging companies to voluntarily commit to implementing all cost-effective efficiency measures and recognizing companies that do so, and
7) providing financial incentives, such as energy or carbon taxes accompanied by an investment tax credit.

The Energy Policy Act of 1992 and President Clinton's Climate Change Action Plan include some of these provisions, but additional action is warranted both to implement initiatives in EPACT and Climate Change Action Plan, and to adopt new initiatives. State and utilities can play an important role in facilitating implementation and delivering services. However, leadership from the Federal Government and cooperation from industry are most critical for maximizing the economic and environmental benefits possible from industrial energy-efficiency improvements.

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