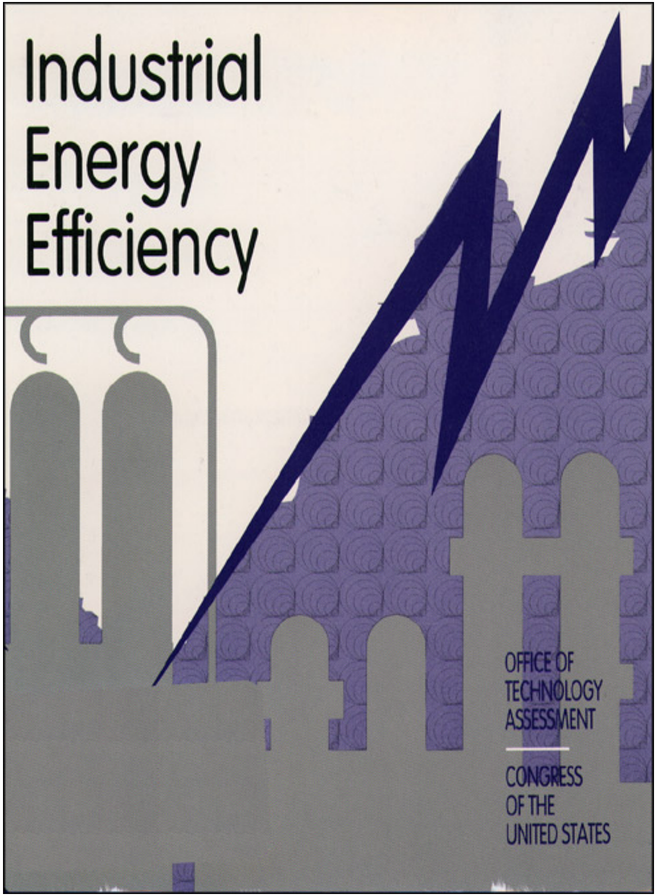
Industrial Energy Efficiency

August 1993

OTA-E-560
NTIS order #PB93-218931
GPO stock #052-003-01336-3



Recommended Citation:
U.S. Congress, Office of Technology Assessment, *Industrial Energy Efficiency, OTA-E-560* (Washington, DC: U.S. Government Printing Office, August 1993).

For sale by the U.S. Government Printing Office
Superintendent of Documents, Mail Stop: SSOP, Washington, DC 20402-9328
ISBN 0-16-041899-2

Foreword

This report was prepared as part of the ongoing OTA assessment, U.S. Energy Efficiency: Past Trends and Future Opportunities, carried out in response to requests from the Senate Committees on Governmental Affairs and on Energy and Natural Resources; the House Committee on Energy and Commerce; and endorsed by the Subcommittee on Environment, Energy, and Natural Resources of the House Committee on Government Operations and by the chairman of the Subcommittee on Environment of the House Committee on Science, Space, and Technology. Other reports in this assessment examine energy use in the Federal Government, residential and commercial buildings, transportation, and the role of utilities in energy efficiency.

This report focuses on energy use in industry, and how government policy can affect it. Trends and patterns in industrial energy use are reviewed, energy-efficient industrial equipment and practices are described, and the factors that influence corporate investment in efficient technologies are explored. Lastly, past Federal efforts to improve industrial energy efficiency are reviewed, and policy options for encouraging the further development and adoption of efficient industrial technologies are discussed.

OTA benefited greatly from the substantial assistance received from many organizations and individuals in the course of this study. Members of the advisory panel provided helpful guidance and advice. Reviewers of the draft report contributed greatly to its accuracy and completeness. OTA and the project staff sincerely appreciate their time and effort.

Roger C. Herdman, Director

Project Staff

Peter D. Blair
Assistant Director, OTA
(beginning February 1993)
Energy, Materials, and International Security Division
Energy and Materials Program Manager

Lionel S. Johns
Assistant Director, OTA
(until February 1993)
Energy, Materials, and International Security Division

John E. Newman
Project Director

ADMINISTRATIVE

Lillian Chapman
Office Administrator

Linda Long
Administrative Secretary

Tina Aikens
Secretary

Advisory Panel

James F. Gibbons, *Chairman*
Dean, Stanford University
Terman Engineering Center

Dale Compton
School of Industrial Engineering
Purdue University

Mark Cooper
Consumers Federation of America

Robert deHaan
Armana Refrigeration, Inc.
retired

Daniel A. Dreyfus
Gas Research Institute

Clark W. Gellings
Electric Power Research Institute

David B. Goldstein
Natural Resources Defense Council

Cheryl Barrington
Regulatory Assistance Project
formerly Commissioner,
Maine Public Utilities Commission

Kenneth Hickman
Applied Systems Division
The York International Corporation

Edward McInerney
GE Appliances Division
General Electric Company

Alan Miller
Center for Global Change
University of Maryland-College Park

Gary Nakarado
Commissioner, Public Utility
Commission of Colorado

John W. Rowe
New England Electric System

Maxine L. Savitz
Garrett Ceramic Components
Garrett Processing Company

Sherwood H. Smith, Jr.
Carolina Power and Light Company

Richard Tracey
Ryland Homes

B.C. Waycaster
Hydrocarbons and Energy
Department
Dow Chemical

Irvin L. White
Battelle, Pacific Northwest
Laboratories

Mason Willrich
Pacific Gas and Electric
Enterprises

James L. Wolf
The Alliance to Save Energy

Eric R. Zausner
Strategic Performance Management

Reviewers

Rob Atkinson
U.S. Congress
Office of Technology Assessment

Samuel Baldwin
U.S. Congress
Office of Technology Assessment

Paul Cicio
Dow Chemical Company

Dwight French
Energy Information Administration
U.S. Department of Energy

Kenneth Friedman
U.S. Department of Energy

Robert Friedman
U.S. Congress
Office of Technology Assessment

Gordon H. Fry
Aluminum Association

Howard Geller
American Council for an
Energy-Efficient Economy

Russell O. Jones
American Petroleum Institute

Alan F. Kessler
Armana Refrigeration, Inc.

Frederick E. Mangelsdorf
Texaco, Inc.

Barry Meyer
Aluminum Association

James E. Reed
Energetic, Inc.

Robert A. Roland
Chemical Manufacturers Association

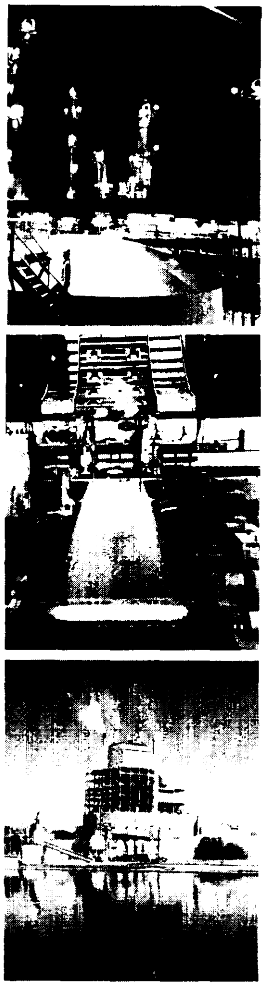
Marc Ross
University of Michigan

Michael E. Samsa
Gas Research Institute

Bruce A. Steiner
American Iron and Steel Institute

W. Ross Stevens Ill
E.I. du Pent de Nemours & Co.

Contents



Introduction and Policy

1

Energy is an integral component of a modern economy. It is an essential ingredient in nearly all goods and services, but its use exacts heavy financial, environmental, and security costs. A key method of reducing energy's costs while retaining its benefits is to use it more efficiently.

Industry is a very large consumer of energy. U.S. manufacturing plants, mines, farms, and construction firms currently consume about 25 quads (quadrillion British thermal units or Btu) of energy each year, about 30 percent of the Nation's total consumption of energy. Industry thus has a major role in making the United States more energy efficient.

Industrial energy use and the opportunities for improving its energy efficiency depend on many technical, economic, institutional, and political factors. Many such factors have changed since the 1970s, when most Federal energy policy was formulated.

- Industrial energy intensity (box l-A) has declined over the last two decades (figure l-l) as a result of improvements in energy efficiency and shifts in industrial structure.
- Industry's petroleum consumption has fallen from its peaks of the late 1970s.
- Prices of petroleum, natural gas, and electricity have declined, when adjusted for inflation, after nearly a decade of increases.
- Utilities have assumed a new role in promoting energy conservation.
- Energy policy has been extended beyond the traditional issues of availability and price to include environmental quality and industrial competitiveness.

Box l-A–Energy Efficiency and Intensity

Efficiency and intensity are terms used to compare energy consumption and product output. Efficiency is a term that is sometimes ambiguous, because it has one meaning in engineering contexts and another in economic contexts. In this report, the terms efficiency and energy efficiency are used to denote the engineering sense of the word, while economlc *efficiency is* used when the economic sense is implied.

Engineering efficiency is the amount of useful work output that a process or a piece of equipment performs with a unit of energy input. It is expressed in units of physical output per unit of energy, or as a percentage of the input energy that is converted into useful output. Engineering efficiency is used to emphasize the engineering performance of equipment and processes. A machine or a process is more energy efficient than another if it uses less energy while yielding the same output. For example, a distillation column that requires 40,000 Btu to process a barrel of crude oil is more technically efficient than one that requires 60,000 Btu per barrel. A motor that converts 90 percent of the electricity input to mechanical energy output is more technically efficient than one that converts 80 percent.

Economic efficiency highlights the cost performance of equipment and processes. A machine or a process is more economically efficient than another if it is less costly and/or yields greater benefits. In the example above, the 40,000 Btu/barrel distillation column is more efficient than the 60,000 Btu/barrel column only if it processes the oil at a lower cost.

Energy intensity focuses on the energy use of entire industries or countries. It is expressed in units of energy per unit of physical or monetary output. It encompasses the effects of both engineering efficiency and indus *structure.* Industrial structure refers to the mix of plants and facilities in the industry or country, and manifests itself in the mix of raw materials, intermediate products, and finished goods that are produced. A country can lower its energy intensity by installing more energy efficient equipment and processes and/or shifting its industrial base away from heavy, processing industries toward light, fabricating ones. Processing raw materials, such as steel and petrochemicals production, generally requires much more energy per unit of output than does fabricating finished goods, such as computer and automobile manufacture.

SOURCE: Office of Technology Assessment, 1993.

- Environmental regulations have become increasingly stringent.
- Market-based policy instruments have attracted increased attention as potential mechanisms for mitigating pollution and influencing energy use.

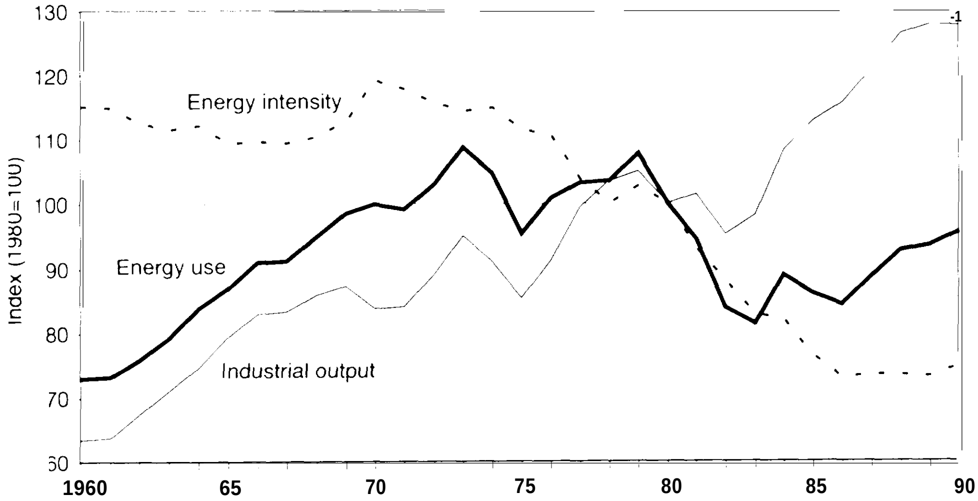
The Energy Policy Act, signed into law in October **1992,** begins to bring Federal energy policy into line with these changed conditions. The law’s effects on industrial energy use, however, are expected to be small.

This report focuses on the prospects for further improving industrial energy efficiency in this new environment. It assesses available technologies for improving energy efficiency, discusses why these technologies are not more widely used, and offers policy options for encouraging their use. Among the questions explored are:

- How does industry use energy? What have been the trends in energy use? What is the outlook for future energy use? (chapter 2)
- What technologies are available to improve industrial energy efficiency? How much energy can they save? (chapter 3)
- How do corporations view energy? What are their incentives and disincentives for using more efficient technologies? (chapter 4)

The remainder of this chapter summarizes the key policy findings of the report and discusses policies Congress might wish to consider in order to further enhance industrial energy efficiency.

Figure 1-1—Industrial Output, Energy Consumption, and Energy Intensity, 1960-90



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

SOURCES: U.S. Department of Energy, Energy Information Administration, State *Energy Data Report,* ***Consumption Estimates 7960-1990,*** **Report No. DOE/EIA-021 4(90), May 1992; and** ***Annua l Energy Review 7991,*** **Report No. DOE/EIA-0384(91), June 1992. Robert P. Parker, U.S. Department of Commerce, Bureau of Economic Analysis (BEA), "Gross Product by Industry, 1977-90,"** ***Survey of Current Business,*** **May** 1993; and BEA, **"National Income and Product Accounts database."**

FINDINGS

I Technical Potential for Saving Energy

1. Industry is a large energy consumer, and efficiency improvements have yielded large energy savings in the past.

In 1990, U.S. manufacturing plants, mines, farms, and construction firms consumed 25.0 quads of fuels and electricity. This accounted for 28 percent of the Nation's total use of fossil fuels, 31 percent of its renewable energy use, and 35 percent of its electricity use (figures 1-2 and 1-3).

However, improvements in industrial processes and shifts away from the manufacture of energy-intensive products have kept consumption 10 percent below its 1973 peak, even though the value of industrial output has grown 30 percent since then.[1] The energy intensity of industrial production has dropped almost one-third from pre-1974 levels, reducing total U.S. energy consumption by about 11 percent.[2] Efficiency gains accounted for between one-half and two-thirds of the energy savings.[3]

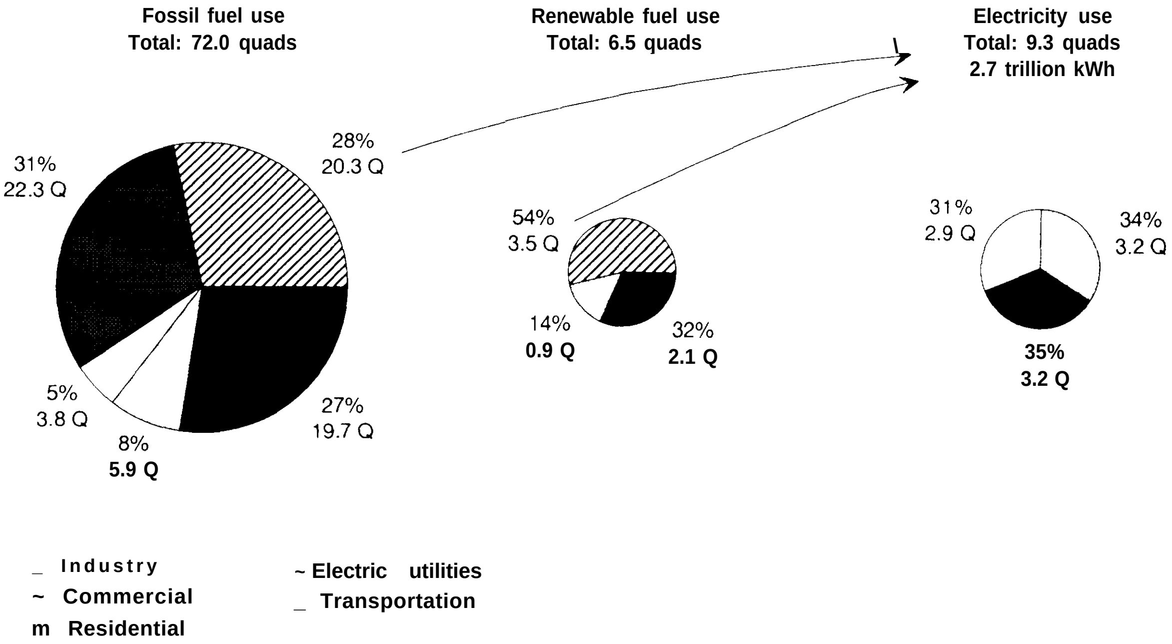
---

[1] Industrial output is measured as gross product originating (GPO), often referred to as value added. The change in GPO is calculated in inflation-adjusted (real) terms.

[2] Industry's energy use in 1990 was about 10 quads less than it would have been had the intensity reductions not occurred.

[3] U.S. Congress, Office of Technology Assessment, *Energy Use and the U.S. Economy, OTA-BP-E-57* **(Washington,DC:** U.S. Government Printing Office, June 1990). J.L. Preston, R.K. Adler, and M.A. Schippcr, U.S. Department of Energy, Energy Information Administration ''Energy Efficiency in the Manufacturing Sector, ' *Monthly Energy Review,* December 1992. G. Boyd, J.F, McDonald, M. Ross, and D.A. Hanson "Separating the Changing Composition of U.S. Manufacturing Production From Energy Efficiency Improvements: A Divisia Index Approach, "The *Energy Journal, vol. 8, No. 2,* pp. 77-96, 1987. C. Doblin, "Declining Energy Intensity in the U.S. Manufacturing Sector, " *The Energy Journal, vol.* 9, No. 2, pp. 109-135, 1988. R. Marlay, "Trends in Industrial Use of Energy, " *Science,* vol. **226,** pp. 1277-1283, 1984.

Figure 1-2—Energy Consumption by Sector, 1990



Arrows indicate fossil fuel and renewable energy sources used to generate electricity. In addition, 6.2 quads of nuclear energy was used to generate electricity. If the energy inputs to electricity generation are allocated to the sectors using the electricity: the industrial sector consumes 32.3 quads of energy (accounting for 38 percent of total U.S. energy use); the residential sector consumes 16.9 quads (20 percent); the commercial sector consumes 13.1 quads (16 percent); and the transportation sector consumes 22.3 quads (26 percent).

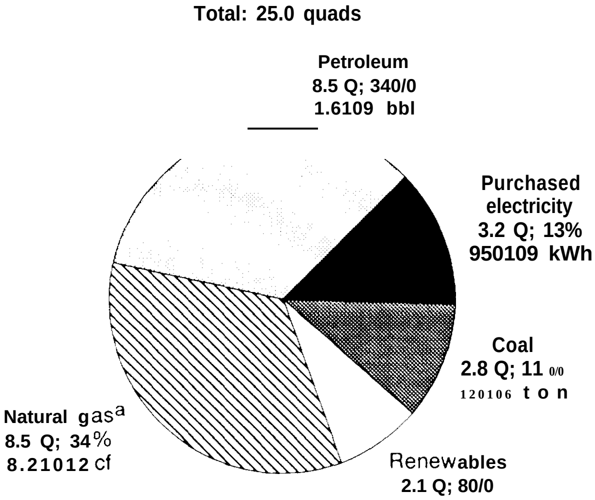
SOURCES: U.S. Department of Energy, Energy Information Administration, State *Energy Data Report, Consumption* Estimates 1960-1990, **Report No. DOE/EIA-0214(90), May 1992;** and *Annual Energy Outlook **1993,*** **Report No. DOE/EIA-0383(93), January 1993.**

2. Many opportunities for further increasing industry's energy efficiency exist, and implementation of them would save substantial amounts of energy.

Chapter 3 describes many technologies and operating practices that could further improve the energy efficiency of industrial production. These range from generic technologies such as high-efficiency motors, cogeneration units, and computerized process controls to industry -specific technologies such as improved alkylation catalysts for petroleum refining, continuous digesters for pulp and papermaking, and ladle metallurgy for steelmaking. Efficiency gains during the late 1970s and early 1980s were achieved by installing improved technologies and instituting better operating practices in new and existing plants, and by closing inefficient facilities. As a result, the easiest and most cost-effective conservation measures, such as improved housekeeping, already have been implemented in most plants.

Implementation of the efficiency measures listed in chapter 3 would clearly yield large energy savings, but estimating how large is difficult. One technique for estimating potential energy savings is to compare the current stock of equipment and processes with the most modem, most efficient technologies available. Chapter 3 estimates that if all petroleum refining, pulp and paper, steel, aluminum, cement, and glass plants

Figure I-3-industrial Energy Consumption by Fuel, 1990



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

SOURCES: U.S. Department of Energy, Energy Information Administration, *State Energy Data Report, Consumption Estimates 1960-1990,* Report No. DOE/EIA-0214(90), May 1992; and *Annual Energy Outlook 1993,* Report No. DOE/EIA-0383(93), January 1993.

were state-of-the-art facilities, they would use 12 to 38 percent less energy than they do today.[4] The energy savings would represent about 10 percent of total industrial energy use at current production levels. Estimates derived by this method are very rough because they are based on a great amount of technical data that is difficult to obtain and keep up-to-date. Moreover, they do not address the economic viability of making every plant state-of-the-art.

Comparing the energy intensity of U.S. industry with its counterparts in other industrialized countries is an often used, but misleading, method for calculating potential energy savings. U.S. industry is more energy-intensive than most other industrialized countries, but this intensity gap is a poor representation of the ground U.S. industry could gain by implementing additional cost-effective, energy-saving technologies. Disparities in energy efficiency account for only apart of the intensity gap. The remainder is caused by differences in countries' industrial makeup and factor price levels (box l-B).

3. ***The cost-effectiveness of energy efficient technologies is the key to their implementation.***

The improved technologies and operating practices listed in chapter 3 enhance energy efficiency only if they are implemented, and they will usually be implemented only if they are cost-effective.[5] A technology or practice is cost-effective if its benefits outweigh its costs, Typical benefits include labor productivity, energy efficiency, and product quality enhancements. Costs include the initial capital outlays, costs of capital, and hidden costs, such as operator retraining and process adjustments and downtime during installation and startup. The costs and benefits depend on the performance, reliability, serviceability of the equipment and processes, and the prices of the energy, raw materials, labor, and capital.

The amount of cost-effective energy savings potential is difficult to assess, because the costs and benefits of technologies and processes are subject to many uncertainties and are often highly site-specific. Some analysts argue that industrial energy efficiency can be improved greatly because, in their view, many cost-effective improvements have not been implemented. In other words, energy efficiency can increase faster than it does in the normal course of business (Finding 4). Other analysts argue that the potential to improve energy efficiency is relatively small. This viewpoint has its roots in neoclassical economics theory that holds that industry irnple-

---

[4] The estimated efficiency gains from using state-of-the-art technologies are: 33 percent for petroleum refining; 17 to 32 percent for pulp and paper production; 34 to 38 percent for steel production; 16 percent for aluminum production 25 percent for cement production and 12 to 31 percent for glass production (see table 3-2). Purchased electricity was accounted for at its primary energy rate of 10,500 Btu/kWh.

[5] Technologies and practices that are not cost-effective are sometimes implemented because of legal requirements or political pressure from the community or stockholders.

Box I-B-international Comparisons of Energy Intensity

Industry is more energy intensive in the United States than in most other industrialized countries, but this does not provide direct evidence of inefficiency. The disparities in energy intensity among the countries are the result of differences in industrial structure, relative factor input prices, as well as energy efficiency.

The higher aggregate intensity of U.S. industry is partly a result of its larger proportion of heavy, energy-intensive sectors such as petroleum refining, chemicals, pulp and paper, steel, and aluminum. Such structural considerations also are valid in industry-specific comparisons. For example, Japanese pulp and paper manufacturers use less energy than U.S. companies to produce a ton of paper, in part because Japan imports, rather than produces, a greater portion of its pulp.

U.S. industry is also more energy-intensive because the prices it pays for energy generally are among the lowest in the industrialized world. Energy prices are linked to efficiency and industrial structure. Low prices increase energy intensity by: 1) acting as a disincentive to save, and 2) attracting energy-intensive industries.

The extent to which differences in structure, prices, and efficiency each explain the higher U.S. energy intensity holds important policy implications.

- Industrial structure differences do not represent an energy problem.
- Factor price *differences* indicate the potential energy savings from using taxes and other price-related measures to adjust the costs of energy, labor, and capital. These savings would result from both improvements in efficiency and shifts in industrial structure.
- Energy efficiency differences not caused by prices reveal the energy savings that would result if U.S. firms made as great a use of cost-effective, energy-saving technologies as do other countries.

Unfortunately, data is inadequate to quantify the effects of countries' industrial structures, factor prices, and efficiency on their energy intensity. international comparisons, therefore, cannot currently be used to estimate how much energy can be saved through improved efficiency. Disparities in energy intensity do little more than suggest the existence of energy-saving opportunities.

ments nearly all cost-effective measures, and that any projects not undertaken must therefore not be cost-effective.

This disagreement raises several considerations: For whom are the actions cost-effective, the corporate energy user or society as a whole? Are industrial decisions always financially rational? These matters are addressed in the Issues section of this chapter.

OTA believes that there exist technologies and practices that would boost efficiency and be cost-effective for corporate energy users to implement. In other words, industrial energy efficiency can be improved. If these cost-effective measures were implemented, annual growth in industrial energy use could be 0.3 to 0.6 percentage points slower than if current policies, practices, and trends continued.

4. ***Industry will likely become more energy efficient on its own, with or without new policy intervention.***

In the normal course of business, industry replaces worn out or obsolete equipment, processes, and operating procedures with new ones. The new technologies and methods are usually more energy efficient, though sometimes changes in raw materials quality, environmental regulations, or other factors cause them to be less so. In general, however, equipment turnover and modernization tends to increase energy efficiency.

Continuing efficiency improvements, coupled with higher growth of light industry relative to heavy industry, are expected to decrease the energy intensity of industry in coming decades. Efficiency will probably, however, increase at a slower rate than observed in the early 1980s, because many improvements have already been implemented. For these reasons, industrial energy intensity use is likely to decline about 1.2 percent annually over the next 40 years absent major changes in the energy prices and public policy.[6] By comparison, intensity fell at a 3.7 percent annual rate from 1974 to 1986.

I Corporate Mechanisms for Saving Energy

5. ***Corporate concern about energy efficiency, though prominent in a few energy-intensive industries, is minimal in most businesses.***

Energy is a fairly small proportion of production costs in most industries, and so historically has played only a modest role in corporate decisionmaking. Energy accounts for 3 percent of total production costs for industry as a whole, and for 5 percent or less of production costs for 86 percent of industrial output.[7] Corporate concern about energy manifests itself when energy price increases or supply limitations are expected, but lies dormant in periods when prices and supplies are stable. Today's relatively low energy prices and stable supplies breed a general lack of corporate attention to energy. Corporate managements are typically less concerned about energy-focused projects than with "line-of-business" items, such as capacity adequacy, operational reliability and flexibility, product development and improvement, cost reduction, labor quality, supply reliability, regulatory compliance, and image enhancement. These nonenergy factors more directly affect corporations' primary goals of profitability, market share, stock price, and management stability.

Energy plays a substantially larger role in the corporate decisions of energy-intensive industries like petroleum refining, petrochemicals, pulp and paper, steel, and aluminum. These industries use large amounts of energy, both as fuel and feedstock. They are very sensitive to, and are constantly concerned with, increasing their energy efficiency, ensuring low energy prices, and minimizing their burden of complying with environmental regulations associated with energy use.

6. ***Indusrial energy use is diverse, and numerous changes are needed to yield large energy reductions.***

Industry's use of energy is heterogeneous. There are thousands of industrial processes, each depending upon a different amount and mix of energy for a variety of services (e.g., motor drive, process heat, steam and electricity generation, electrolysis, and product feedstocks). Moreover, industries vary greatly in their overall level of energy use, because of differences in industry scale and energy intensity. Four industries are particularly large energy users: petroleum refining, chemicals, primary metals-mainly steel and aluminum, and pulp and paper. They account for 68 percent of total industrial energy use and 78 percent of manufacturing energy use (figure 1-4).

The methods available for raising energy efficiency are as varied as the ways industry uses energy, but can be grouped into four categories:

- *Operational* changes—maintenance, housekeeping, and accounting;

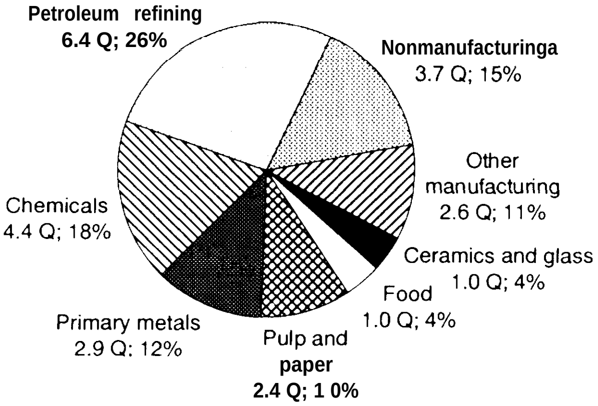
---

[6] Based on the reference case scenarios in U.S. Department of Energy, Energy Information Administration, Energy Consumption *and Conservation Potential: Supporting Analysis for the National Energy Strategy,* Report No. SR/NES 9002, December 1990; and Alliance to Save Energy, American Council for an Energy-Efficient Economy, Natural Resources Defense Council, and Union of Concerned Scientists in consultation with the Tellus Institute, *America's Energy Choices: Investing in a Strong Economy and a Clean Environment: Technical Appendixes* (Cambridge, MA: Union of Concerned Scientists, **1992). These** studies are discussed in chapter 2.

[7] U.S. Department of Commerce, Bureau of the Census, 1990 *Annual Survey of Manufactures: Statistics for Industry Groups and Industries,* Report No. M90(AS)-1, March 1992; 1987 *Census of Agriculture: United States Summary and State Data,* Report No. AC87-A-5 1, November 1989; 1987 *Census of Mineral Industries: General Summary,* Report No. MIC87-S- 1, March 1991; 1987 *Census of Construction Industries: United Srafes Summary,* Report No. CC87-I-28, March 1990.

Figure I-4—industrial Energy Consumption by Industry Sector, 1988

Total: 24.2 quads



a Nonmanufacturing includes natural gas used as lease and plant fuel, but excludes agricultural uses of natural gas.

SOURCES: U.S. Department of Energy, Energy Information Administration, *Manufacturing Energy Consumption Survey, Consumption of Energy 7988,* Report No. DOE/EIA-0512(88), May 1991; and *State Energy Data* Report, *Consumption Estimates 1960-1990,* Report No. DOE/EIA-0214(90), May 1992.

- *Equipment* changes-equipment improvement, equipment sizing, fuel switching, and energy management systems;
- *Process refinements and changes*-equipment integration, general automation, cogeneration, quality control, waste minimization and utilization, recycling, raw materials substitution; and
- *Product* shifts-product demand, domestic production and trade, product refinement, materials substitution, product quality and performance.

The reasons for these changes may or may not be related to energy, but energy use is affected nonetheless.

There is no single technology that can conserve large amounts of energy in all industries. A few technologies and practices (e.g., high-efficiency motors, steam and electricity cogeneration, process integration, recycling, and energy management systems) can improve energy efficiency to some extent on a broad basis, but most are applicable to a narrow range of industrial facilities.

7. ***Many projects undertaken primarily for nonenergy reasons produce energy efficiency gains as a secondary consequence.***

Modern equipment and processes tend to be more energy-efficient than older ones. Likewise, well-maintained machines are more efficient than those that have been kept up poorly. Therefore, projects that involve equipment turnover, maintenance, or adjustment often increase energy efficiency. Even projects undertaken to improve nonenergy characteristics such as production costs, product quality, and environmental compliance often have the side benefit of increasing energy efficiency.

Potentially, the greatest increase in energy efficiency may not be the result of direct efforts to reduce energy consumption but of indirectly pursuing other economic goals. This feature compensates, to some extent, for the generally low corporate concern for energy issues (Finding 5).

8. ***General capital investment plays a central role in improving energy efficiency.***

Energy efficiency can still be improved through greater attention to housekeeping and maintenance, but most of the gains that come from these management practices have already been realized. The key, therefore, to substantial increases in energy efficiency is investment in plants and equipment. Large efficiency increases come from major investments in new plants and processes. Smaller gains are obtained from retrofitting and optimizing existing facilities.

General capital investment is perhaps the most important route to increased energy efficiency, given the low corporate concern about energy (Finding 5) and the secondary efficiency gains yielded by nonenergy investments (Finding 7). In addition to yielding its own energy efficiency benefits, investment in plant and equipment can be a springboard for adopting other more energy-focused measures. Energy projects can be more cost-effective when coupled with larger projects, because the marginal costs of the extra effort are small. The Office of Technology Assessment (OTA) identified the importance of investment in

Industrial Energy Use (1983).[8] That study examined energy use in the pulp and paper, petroleum refining, chemicals, and steel industries, It concluded that substantial gains in energy efficiency from technical innovation were possible, and that economic growth and the promotion of general corporate investment were the most effective ways of realizing those gains. This conclusion is still valid.

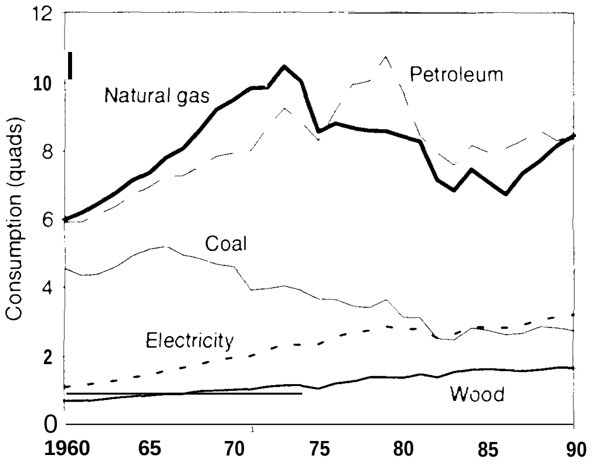
9 Policy Considerations for Saving Energy

9. The ability of electric utilities to influence industrial ***energy*** *efficiency has been increasing.*

Industry is using an increasing amount of electricity, both in absolute terms and relative to other fuels (figure 1-5). Use of electric technologies is expected to continue growing at the expense of fossil-fired technologies because of air quality concerns. Existing environmental regulation, such as the Clean Air Act, will continue to push industrial processes toward decreased dependence on fossil fuel. This trend gives electric utilities and State regulators increasing influence over the energy efficiency of industrial energy users. It also reduces the pool of technologies that would be responsive to fossil fuel and clean air policies. In other words, the potential direct policy influence over industrial energy use is gradually shifting from the Federal level to the State level, where utilities are regulated.

10. Energy policy is increasingly addressing multiple objectives: energy security, environmental quality, and industrial competitiveness.

Figure 1-5--Industrial Energy Consumption by Fuel, 1960-90



SOURCES: U.S. Department of Energy, Energy Information Administration, *State Energy Data Report, Consumption Estimates 1960-1990,* Report No, DO13EIA-0214(90), May 1992; and Annual *Energy Review 1991*, Report No. DOE/EIA-0384(91), June 1992. U.S. Department of Commerce, Office of Business Analysis, "National Energy Accounts database."

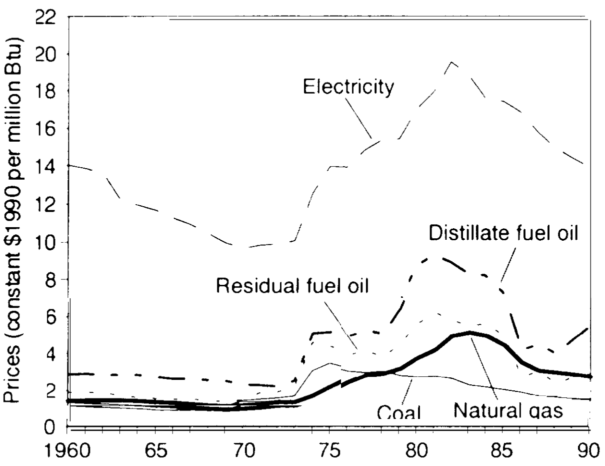
Industrial energy use is a mature policy area. There have been policy initiatives in place since the late 1970s. In the early years, the driving force behind policy was market security, keeping energy available and inexpensive. Increasingly, the policy emphasis is shifting toward environmental quality and industrial competitiveness. This trend is likely to intensify as concerns about carbon emissions from fossil fuel use grow and global trading and investment increase. These additional policy objectives raise the policy weight of energy issues. They draw greater attention to, and demand greater action from, energy policy. However, they also place extra constraints on policy, because they narrow the range of viable technical options. Furthermore, the multiple objectives require enhanced coordination among many Federal and State programs.

Energy efficiency can play a central role in this policy environment. Its strength lies in the links it forges between security, environmental, and competitiveness objectives. The links arise because energy efficient technologies and processes not only use less energy than standard technologies, but also often have lower costs and pollute less.

---

[8] U.S. Congress, Office of Technology Assessment, *Industrial Energy Use, OTA-E-198* (Washington, DC: U.S. Government Printing Office, June 1983).

Figure 1-6—Industrial Energy Prices, 1960-90



1990 prices

Distillate fuel oil	$0.79/gallon	$5.68/million Btu
Residual fuel oil	$0.46/gallon	$3.10/million Btu
Natural gas	$3.03/1,000 cf	$2.94/million Btu
Coal	$40.71/short ton	$1.69/million Btu
Electricity	$0.047/kWh	$13.92/million Btu

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

POLICY CONTEXT

I Technical and Economic Trends

Since the oil embargoes of the early 1970s, U.S. industrial energy use has evolved considerably. Fuel preferences have shifted, energy prices have risen and then fallen, and energy intensity has declined.

FUEL USE

Fossil fuels, especially petroleum, were the focus of much energy policy concern in the 1970s. Industrial consumption of fossil fuels has generally declined in the last two decades, though natural gas and petroleum still remain the two largest energy sources (figure 1-5). Petroleum use increased until 1979 and then declined until 1983. It has been rising in recent years, mostly because of its increased use as a feedstock. Overall industrial petroleum consumption, however, remains lower than in the 1970s by several measures: in total barrels used, as a percentage of total industrial energy use, and as a share of total U.S. petroleum use.[9] Natural gas use declined in most years until 1986 and has been increasing since. Coal consumption fell steadily until the mid-1980s and has been fairly level since. Electricity use rose steadily until 1979, fluctuated until 1988, and has been rising since. It is now a larger source of industrial energy use than coal. Wood, waste energy, and alcohol fuels use rose steadily until 1985 and have been fairly level since. Biofuels are still, however, much less used than traditional fuels. 9

PRICES AND SUPPLIES

Energy prices and supply availability were also of great policy concern during this period. Prices rose throughout much of the 1970s, reaching historic high levels in the late 1970s and early 1980s (figure 1-6). They then declined during the mid-1980s, offsetting much of the rise in the previous decade. From 1982 to 1990, prices fell 47 percent for oil, 43 percent for natural gas, 38 percent for coal, and 29 percent for electricity.l0 The 1991 Persian Gulf War prompted forecasters to reexamine energy price projections, especially those for oil. Many forecasters, though, continue to predict modest increases in energy prices.

Energy supplies were generally stable throughout most of the 1980s. Markets remained calm except for a brief period during the 1991 Gulf **war.**

---

[9] **In 1990, industrial consumption** of petroleum was approximately 8.5 quads, representing 33.9 percent of total industrial energy use and 25.3 percent of U.S. petroleum use. In 1979, the peak year for industrial consumptionof use, consumption was approximately 10.8 quads, representing 39.5 percent of total industrial energy use and 29.0 percent of U.S. petroleum use.

[10] N references t. pfice Changm in this report are calculated in inflation-adjusted (real) t~s.

ENERGY INTENSITY

Prior to the early 1970s, the energy intensity of industrial production remained relatively steady (figure 1-1). Growth in energy use was directly coupled with economic growth. From 1974 to 1985, energy intensity declined by 30 percent and the old relationship between industrial energy consumption and economic growth was broken. This "delinking" of energy use and growth was the result of: 1) improvements in energy efficiency, and 2) shifts in industrial structure caused by technical and economic changes.

Energy efficiency increases came from general housekeeping, regular maintenance, energy management systems, equipment changes, and process refinements and changes. These operational changes were frost prompted by high energy prices and supply instabilities, but were continued because of environmental mandates and cost-competitiveness challenges.

Shifts in industrial structure have changed the market basket of goods and services produced in the United States. For example, the production of steel and petrochemicals has declined relative to that of computers and financial services. The transition has been the result of changing product demand patterns, changing production networks, and the increasing globalization of business.[11] It has had a significant effect on industrial energy intensity, because industry's component sectors vary in their energy intensity by about a factor of 200.

Studies have shown that roughly one-third to one-half of the decline in manufacturings energy intensity between the mid-1970s and mid-1980s can be attributed to a shift in the mix of output, with ''smokestack' industries declining and lighter manufacturing industries gaining.[12] The remaining portion of the intensity decline can be attributed to energy efficiency improvements.

Since 1986, the decreases in U.S. energy intensity have virtually stopped. This suggests that energy consumption has once again become directly coupled with industrial output, albeit at a lower level than existed before 1974. The pool of potential efficiency-enhancing measures has decreased, because many improvements have already been implemented.

Nevertheless, the frontier of energy efficiency can still be advanced, despite the low and generally stable energy prices. Past improvements have "primed the pump" for further technological innovation. Considerable future gains in efficiency are possible with existing technology, and more substantial gains are likely with technologies currently under development.

Q Institutional Trends

Utilities are playing an increasing role in energy conservation because of the growing need for effective load management.[13] Electric utilities have used load control measures for more than 50 years, but interest in these measures increased significantly during the turbulent energy markets of the 1970s and 1980s. Rising construction costs, troublesome nuclear programs, cost disallowances, wholesale rate hikes, and new environmental requirements have prompted many utilities and commissions to employ integrated resource planning (IRP) methods and demand-side management (DSM) programs. Using DSM techniques, such as customer education, alternative pricing, and equipment rebates, utilities encourage their customers to conserve energy and shift

---

[11] OTA tis analyzed the structural changes in the U.S. economy and their implications for energy use in: *Energy Use in the U.S. Economy*, op. cit., footnote 3 and U.S. Congress, Office of Technology Assessment, *Technology and the Amen"can Economic Transition: Choices for the Future, OTA-TET-283* (Washington, DC: U.S. Government Printing Office, May 1988).

[12] Supra footnote 3.

[13] The role of electric utility programs is covered in U.S. Congress, Office of Technology Assessment, *Energy Use: Challenges and Opportunitiesfor Electric Utilities*, OTA-E-561 (Washington DC: U.S. Government Printing Office, in press).

usage to off-peak periods.[14] These efforts help utilities manage their load and reduces the need for new generating capacity. Energy efficiency advocates hold that these strategies are often cheaper for rate payers, and better for the environment and society, than building new power plants. Some industrial companies worry that DSM programs are costlier than the energy they save, and will thus lead to higher electricity rates.

Public utilities are well-positioned to promote the adoption of more energy efficient technologies. Their integrated operations, technical expertise, established ties to customers, and familiarity with customer energy use equip them with the technical skill, marketing tools, and information to identify opportunities to save energy. Their special status as regulated public utilities offers access to capital, a relatively secure cash flow, and a concomitant responsibility to provide cost-effective and reliable service to their customers. This status also makes them attractive targets for policy initiatives in pursuing energy efficiency.[15]

~ Political Trends

Energy policy concerns have expanded beyond the traditional issues of prices and availability to include issues of environmental consequences and industrial competitiveness. Acid rain, nuclear waste, carbon dioxide ($C0_2$) emissions, and other local and global environmental topics have supplanted security, in many instances, as the central issue in energy policy. Energy efficiency is an important policy option in this new multiobjective environment. Energy efficient technologies and processes use less energy, have lower costs, and often pollute less than standard technologies; furthering the three objectives of energy security, environmental quality, and industrial competitiveness.

A related development is the growing interest in using market mechanisms and other alternative approaches to deal with environmental problems. As U.S. environmental compliance costs have risen, Congress has come under increasing pressure to move away from traditional regulatory programs to newer and more economically efficient approaches. Alternatives to, or augmentation of, traditional command and control policy instruments can take many forms. These include ‘‘market-based’ or economic approaches, such as marketable pollution permits or emissions fees. Information programs are another set of alternatives. Even among what is traditionally termed “command and control, ” there is a wide variety of alternative approaches, including technology-based standards, design standards, end-of-pipe performance-based standards, and use restrictions. Implementation of these sorts of approaches to environmental problems would have direct and indirect impacts on industrial energy use.[16]

I Stakeholders and Interested Parties

Many individuals and organizations are interested in the issue of industrial energy use and efficiency. First and foremost are the industrial companies themselves. Their profitability depends in large part on keeping production costs low, which means being efficient with respect to energy and all other factor inputs. Attention to energy efficiency varies depending on company size and nature of business. Companies in the process industries and the materials-production sector, where energy is a large cost factor, pay close attention to their energy situation. Large companies in these industries often conduct in-house research and development to come up

---

[14] Electric power Research Institute, *Demand Side Management, Volume 5: Industrial Markets and Programs,* EPRI EA/EM-3597 (Palo Alto, CA: Electric Power Research Institute, March 1988).

[15] OTA, *Energy Use: Challenges and Opportunities for Electric Utilities*, op. cit., footnote 13.

[16] OTA is assessing the effectiveness Of coremand-and-control regulations and the appropriateness of alternative policy instruments for handling various pollution problems in its study entitled New *Approaches to Environmental Regulation.*

with processes that are more efficient than their rivals. In less energy-intensive industries, concern about energy use is generally low.

Companies have numerous trade associations that provide them with technical support and represent their interests to the government and the public. Trade associations representing energy-intensive industries actively monitor energy policy developments. Among these are: the American Iron and Steel Institute, the Aluminum Association Inc., the Chemical Manufacturers Association, the American Petroleum Institute, the American Paper Institute Inc., and the Primary Glass Manufacturers Council. There is also a group, the Electricity Consumers Resource Council (ELCON), that focuses specifically on the energy interests of large industrial electricity users. ELCON works to curb electricity rate increases for industrial companies. It conducts research on actions affecting electricity rates and promotes its findings to suppliers, regulators, and State and Federal Government bodies. Energy-intensive companies and energy-producing companies are also represented by Global Climate Coalition. This association of business trade associations and private companies was formed to coordinate the active involvement of U.S. business in the scientific and policy debates concerning global climate change issues.

Electric and gas utilities, and the organizations associated with them, play a large role in industrial energy use. Utilities supply a large portion of the energy used by industry. In addition, many of them actively promote energy conservation. Public utility commissions (PUCs) set energy price rates and establish the incentives that encourage or discourage utilities' DSM efforts. Another group, interveners, represents the interests of particular groups at PUC ratemaking hearings. Among them are those who act on behalf of industrial energy users. There are others that represent environmental constituencies.

Utilities have two research organizations to assist them with their programs, the Electric Power Research Institute (EPRI) and the Gas Research Institute (GRI). These organizations conduct research into new or improved technologies that enhance the energy efficiency, cost-effectiveness, product quality, and environmental cleanliness of industrial processes. EPRI, which budgeted $9.2 million for industrial research in 1993, has programs researching technologies to enhance the productivity, product quality, and waste and water treatment characteristics of materials production and fabrication industries, process industries, and municipal services.[17] GRI, which budgeted $21.1 million for industrial research in 1993, has efforts aimed at industrial combustion technologies; processing equipment for the metals, glass, brick, cement, ceramics, and advanced materials industries; and sensor and control systems for industrial processes.[18] These organizations also assist their member utilities with design and implementation of DSM programs.

Environmental advocates are also involved. Among those who focus on energy use and its implications for the environment and the economy are: the Alliance to Save Energy (ASE), the American Council for an Energy-Efficient Economy (ACEEE), the Rocky Mountain Institute (RMI), and the Natural Resources Defense Council (NRDC). These organizations conduct research, disseminate information, and promote policies to encourage the use of energy efficient equipment and processes.

The Federal Government has several programs to improve the energy efficiency of the Nation's industrial sector. The lead agency in this effort is the U.S. Department of Energy (DOE), in particular the Office of Industrial Technologies of the Office of the Assistant Secretary for Energy

---

[17] Electric Power Research Institute, *Research, Development, and Delivery Plan 199.? -1997,* January 1993.

[18] Gas Research Institute, *1993-1996 Research and Development Plan and 1993 Research and Development program,* April 1992.

Efficiency and Renewable Energy .19 The Office of Industrial Technologies adminisiers dyrtd sters an auditing program for small-and medium-sized manufacturers, and sponsors cost-shared research at university and government laboratories into technologies that are energy-efficient, fuel-flexible, waste-minimizing, and waste-utilizing. DOE's Energy Information Administration (EIA) has responsibility for gathering and analyzing data on industrial energy consumption. DOE and the U.S. Environmental Protection Agency (EPA) cosponsor a program to demonstrate energy efficient technologies to potential industrial users. EPA also runs a program that publicly recognizes companies that install energy efficient lighting in their offices and plants. The Bonneville Power Administration (BPA), a Federal power-marketing authority, has a program to improve the electricity efficiency of aluminum producers in its service area in the Pacific Northwest.

Many States also have programs to provide technical assistance to companies. There are information programs to help industrial companies keep abreast of developments in energy efficiency and pollution prevention technologies. In addition, some States have agencies that research and develop energy efficient equipment and processes. These agencies are typically funded by utilities or State revenues or both, and they work closely with utilities, regulators, and State officials to target research areas most relevant to the State's needs.

~ Current Federal Policy

Many Federal energy initiatives of the late 1970s dealt with industrial energy use. Among them were:

- the Energy Policy and Conservation Act (EPCA), Public Law 94-163;
- the National Energy Conservation Policy Act (NECPA), Public Law 95-619;
- the Public Utility Regulatory Policies Act of 1978 (PURPA), Public Law 95-617;
- the Energy Tax Act of 1978, Public Law 95-618; and
- the Powerplant and Industrial Fuel Use Act of 1978, Public Law 95-620.

These policies focused on mitigating the economic and strategic effects of the oil shocks. Some programs-like energy-auditing, nonutility power generation rules, and conservation research efforts—still exist. Others, such as energy conservation targets, investment tax credits, and boiler-fuel restrictions, have been discontinued.

Between 1979 and 1992, there were few new policy initiatives specifically addressing industrial energy use. Two laws from this period, the Steel and Aluminum Energy Conservation and Technology Competitiveness Act of 1988, Public Law 100-680, and the Department of Energy Metal Casting Competitiveness Research Act of 1990, Public Law 101-425, sought to enhance the competitiveness of specific industries by focusing on Federal energy research, development, and demonstration (RD&D) efforts.

The next major energy law that contained industrial initiatives was the Energy Policy Act of 1992 (EPACT), Public Law 102-486. Among this legislation's provisions that focus on industrial energy use are those for: motor standards, trade association-based targeting, utility planning and conservation, and greenhouse-gas emissions tracking (box l-C). It is estimated that the industrial energy savings from this law will be about 0.25 quads per year by 2000 and 0.77 quads per year by 2010.[20]

---

[19] The Office of Energy Efficienc, and Renewable Energy was renamed from the Office of Conservation and Renewable Energy in early 1993.

[20] Based on estimates from H. Geller, S. Nadel, and M. Hopkins, *Energy Savings Estimates From the Energy Efficiency provisions in the Energy Policy Act of 1992* (Washington DC: American Council for an Energy Efficient-Economy and Alliance to Save Energy, November 1992).

Box I-C-Industrial Energy Use Provisions of the Energy Policy Act of 1992

Technology research, development, demonstration, and commercial application (Sections 2101,2103, 2105,2106,2107,2108, 2201, and 2202)

The Department of Energy is directed to conduct a 5-year program of cost-shared RD&D and commercial application activities that: 1) accelerate development of technologies that will increase energy efficiency and improve productivity, 2) increase the use of renewable energy, and 3) reduce environmental impacts in the industrial sector. Such activities may be carried out for any industrial technology, but pulp and paper production processes, electric drives, and pollution-prevention technologies and processes are specified outright. Funding is extended for existing programs in the steel, aluminum, and metal-casting industries. in addition, DOE is authorized to undertake joint ventures to encourage the commercialization of technologies developed under its RD&D and commercial application programs. DOE is also directed to conduct a 5-year program including field demonstrations to foster the commercialization of advanced manufacturing technologies and techniques for processing, synthesizing, fabricating, and manufacturing advanced materials. The goal of these programs is to generally improve economic growth, competitiveness, and energy efficiency.

Motor standards, testing, and labeling programs (Section 122)

Minimum energy-efficiency standards and testing procedures are specified for motors sold in the United States after October 1997. The standards and tests apply to general purpose motors from 1 to 200 horsepower. Depending on motor size, the standards are 1 to 6 percentage points higher than the average efficiency of standard motors and roughly equivalent to the least efficient models of high-efficiency motors. DOE is charged with prescribing labeiing rules that indicate the efficiency of motors on their permanent nameplates and in marketing materials, such as equipment catalogs.

Reporting, voluntary targeting, and public recognition (Sections 171 and 131)

The frequency of DOE's data collection on industrial energy use (the Manufacturing Energy Consumption Survey) is raised from a triennial basis to at least once every 2 years. Collection of data on nonpurchased energy sources such as solar, wind, biomass, geothermal, waste byproducts, and cogeneration is to be improved. Also, the surveys are to be expanded in order to improve the evaluation of the effectiveness of energy efficiency policies and programs. The expanded surveys are to include questions regarding participation in government and utility-conservation programs and the use of energy efficiency and load-management programs.

DOE is authorized to make grants of up to $250,000 to industrial associations for support of workshops, training seminars, handbooks, newsletters, databases, or other such activities to improve industrial energy efficiency. To be eligible for these grants, an industry association must establish a voluntary energy-efficiency improvement target program. DOE is instructed to establish an awards program to recognize those industry associations or individual companies that have significantly improved their energy efficiency. DOE must report to Congress regarding the costs and benefits of establishing mandatory reporting and voluntary targets for energy-intensive industries.

Utility efforts that encourage industrial efficiency (Sections 132 and 1912)

DOE is authorized to make grants to States for promoting the use of energy efficient technologies in industry, training individuals in conducting process-oriented industrial assessments, and assisting utilities in developing, testing, and evaluating industrial energy-efficiency technologies and programs. To be eligible for such grants, States must have considered implementing Federal standards with respect to integrated resources planning (IRP) and demand-side management (DSM). in addition, the States must encourage utilities to provide companies with process-oriented assessments and with financial incentives for implementing energy efficiency improvements. The assessments are to be used to identify opportunities in industry for improving energy efficiency, reducing

(Continued on next page)

Box I-C-Industrial Energy Use Provisions of the Energy Policy Act of 1992-(Continued)

environmental impact, increasing competitiveness, enhancing product quality, and using renewable energy sources in production processes and in lighting, heating, ventilation, air conditioning, and associated building services. The Internal Revenue Code is amended to exclude from gross income 40 to 65 percent of the value of subsidies provided by utilities to industrial customers for the purchase or installation of energy-conservation measures.

Auditing and insulation (Section 133)

DOE is to establish voluntary guidelines for the conduct of energy efficiency audits and the installation of insulation in industrial facilities.

Electricity transmission access (Sections 721 and 722)

The Federal Energy Regulatory Commission is authorized to order utilities to wheel wholesale power for electricity generators when it is in the public interest. Wholesale wheeling is the activity of moving electric power from a generator to a utility via the transmission system of another utility. Access to transmission services allows cogenerating facilities to sell their power outside of their utilities' service area. This makes cogeneration more attractive, because the excess power can be sold to utilities offering higher prices than those of the local utility.

Greenhouse policy planning (Sections 1604 and 1605)

DOE must report to Congress on alternative policy mechanisms for reducing the generation of greenhouse gases. Among the mechanisms to be considered are Federal standards for energy efficiency for industrial processes. The policy assessment must include a short-run and long-run analysis of the social, economic, energy, environmental, competitive, labor, and agricultural costs and benefits of such policies. DOE must also develop a voluntary reporting system to track greenhouse-gas emissions and their reductions. Reported reductions could potentially be credited against any future mandated cuts.

SOURCE: Energy Policy Act of 1992, U.S. Houea of Representatives, Conference Report to aooompany H.R. 776 Report 102-101S, Oct. 5, 1992.

Most programs that focus on industrial energy use are administered by DOE. Other agencies such as EPA are also involved, but to a lesser extent.

ENERGY AUDITING AND TECHNICAL ASSISTANCE

Energy audits conducted by outside experts are a direct way of informing companies, especially smaller ones, about energy-saving techniques. The Federal Government provides free audits to small and medium-sized companies through DOE's Energy Analysis and Diagnostic Centers (EADCS) located at 25 universities. Faculty and students perform energy audits and make energy-saving recommendations to the manufacturers. The program is funded at $3.9 million (FY 1993).[21] From its initiation in 1976 until 1992, about 4,100 energy audits were performed in 37 States. These audits have yielded energy savings of 77 trillion Btu and cost savings of $419 million at a cumulative cost to the Federal Government of $18 million.

EPACT extends DOE's role in auditing. The act requires the agency to establish voluntary guidelines for the conduct of energy efficiency audits and the installation of insulation in industrial facilities.

The Federal Government also offer companies technical assistance through the seven National Institute of Standards and Technology (NIST) Manufacturing Technology Centers (MTCs). These

---

[21] U.S. Department of Energy, *Congressional Budget Request, FY 1994, Volume 4*, April 1993.

centers work directly with small fins, both on-site and in central demonstration facilities, to help improve their competitiveness through use of advanced technologies and techniques. Other Federal technology extension services and information programs include: the National Appropriate Technology Assistance Service in DOE; the Extension Service in the Department of Agriculture; and various pollution-prevention hotlines, databases, and publications in EPA.

REPORTING AND TARGETING

Energy-use reporting and targeting programs encourage energy efficiency by giving it a higher profile in industrial firms. A program in which large energy-intensive manufacturers reported their annual energy use to the government and agreed to voluntarily improve their energy efficiency to specified targets was established by EPCA in 1975 and expanded by NECPA in 1978.[22] Companies reported the energy data to their trade associations, which compiled it and then sent it on to the government. The program was begun in 1977 and eliminated in 1986.[23] The program's data-collection effort was reestablished in the form of the Manufacturing Energy Consumption Survey (MECS). Since 1985, MECS data has been collected every 3 years. Unlike the earlier program, companies report the data directly to DOE.

EPACT raises the frequency of MECS to at least once every 2 years. It also expands the scope of data collection in order to improve coverage of renewable fuels and to enable better evaluation of energy efficiency policies and programs. The act authorizes grants to be made to industrial associations that establish voluntary energy-efficiency improvement target programs for their members. The grants are for support of workshops, training seminars, handbooks, newsletters, databases, or other such activities to improve industrial energy efficiency. The act also requires DOE to develop a voluntary reporting system to track greenhouse-gas emissions and their reductions. Reported reductions could potentially be credited against any future mandated cuts.

PUBLIC RECOGNITION

EPA's Green Lights program, begun in January 1991, enlists major corporations to install more energy efficient lighting in their facilities in exchange for technical assistance and public recognition. Program participants voluntarily agree to retrofit lighting in at least 90 percent of the total square footage of their U.S. facilities within 5 years of signing the Green Lights agreement. Retrofits are required only in cases where they will be cost-effective and will not compromise lighting quality. As of September 1992, over 500 companies had enrolled in the program.

EPACT instructs DOE, as part of its industry association grants program, to establish an awards program to recognize those industry associations or individual companies that have significantly improved their energy efficiency.

EQUIPMENT STANDARDS, TESTING, AND LABELING

In 1978, NECPA instructed DOE to report to Congress on the practicability and effects of minimum energy efficiency standards for electric motors. Early drafts, written during the Carter administration, showed that motor efficiency standards were likely to be beneficial. The final report, written during the Reagan administration, concluded that the potential benefits would be small and did not recommend standards. EPACT mandates minimum efficiency standards for gen-

---

[22] A similar program had been developed in 1974 by the U.S. Department of Commerce. It was a voluntary program that encouraged manufacturers to: obtain the commitment of top management to energy conservation; undertake a thorough energy audit; develop voluntary conservation goals and programs designed to meet them; and conduct energy awareness campaigns aimed at employees, suppliers, customers, and the community at large.

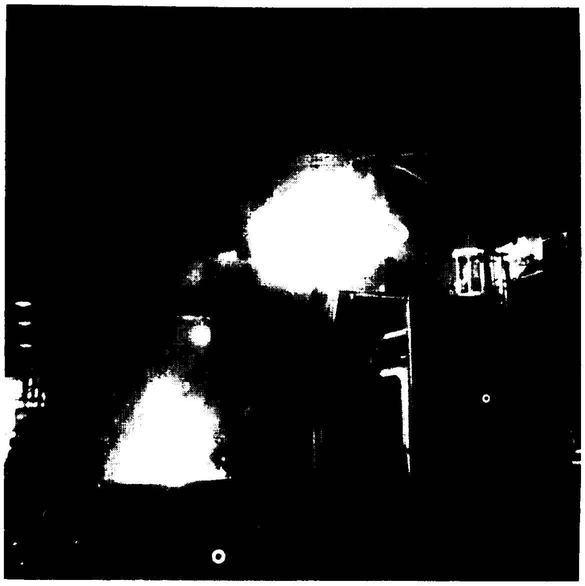
[23] Two trade associations, the American Paper Institute and the Chemical Manufacturers Association, have continued collecting the energy data for their own purposes.

eral purpose motors sold in the United States after October 1997.

TECHNOLOGY RESEARCH, DEVELOPMENT, AND DEMONSTRATION

Industrial energy efficiency can be improved by implementing current state-of-the-art technologies, but continuous advancement requires a constant flow of new and improved technologies. Many organizations, including technology-using companies, equipment suppliers, utility groups, and government and academic laboratories conduct RD&D to advance production technologies and processes.

The Federal Government's principal RD&D directed at the energy use of industrial technologies is administered by the DOE Office of Industrial Technologies. The stated mission of the effort is to: 1) increase energy end-use efficiency, promote renewable-energy use in industrial applications, and improve industrial productivity; 2) reduce industrial and municipal waste-stream volume and the associated environmental impact; and 3) identify, support, and transfer the results of its research. Potential projects are identified in collaboration with private industry, and selected for funding based on their ability to improve energy efficiency and fuel flexibility in industry. Priority is given to technologies not being aggressively pursued by the private sector. The research is carried out under contract with university and government laboratories, or cost-shared contracts with private industry. DOE has a technology-transfer role, but much of the information dissemination and technology promotion is actually left to the organizations that perform the research.


U.S. DEPARTMENT OF ENERGY

Tapping from pilot-scale research smelter near Pittsburgh. The direct steelmaking program is funded by the American Iron and Steel Institute and the U.S. Department of Energy,

In FY 1993, DOE's industrial RD&D program was appropriated at$112.8 million for work in the areas of industrial waste, municipal solid waste, cogeneration, materials processing, separation techniques, sensors and controls, bioprocessing, enabling materials, improved combustion efficiency, and process heating and cooling (see appendix A for details).[24] A funding increase of 22 percent has been requested for FY 1994. Part of the program, the $17.9 million (FY 1993) "Metals Initiative" directed at technologies for the steel, aluminum, and metals-casting industries, was explicitly mandated by Congress.[25] DOE estimates that its research efforts in industrial technologies result in energy savings of 80 trillion Btu per year; competitiveness benefits of 8,300 person-years of increased employment and $540 million of increased capital productivity; and pollutant emissions reductions of 6 million tons of particulate, 32 million tons of sulfur

---

[24] U.S. Department of Energy, op. cit., footnote 21.

[25] These programs are mandated by the "Joint Resolution making further continuing appropriations for the fiscal year 1986' (Public Law 99-190), the Steel and Aluminum Energy Conservation and Technology Competitiveness Act of 1988 (Public Law 100-680), the Department of Energy Metal Casting Competitiveness Research Act of 1990 (Public Law 101425), and the Department of the Interior and Related Agencies Appropriations Act, 1991 (Public Law 101-512).

[26] U.S. Department of Energy, Office of Industrial Technologies, *Summary of Program Impacts*, December 1992.

dioxide, 17 million tons of nitrogen oxides, and 7 billion tons of carbon dioxide (1991).[26]

From FY 1976 through 1992, DOE spent $854 million (current dollars) for industrial RD&D. The Department estimates that the cumulative energy savings of more than 35 completed industrial projects have been approximately 419 trillion Btu, representing a net production cost savings for industry of $1.15 billion (current dollars). DOE expects these projects to save almost 1.1 quads of energy annually by 2010, The more successful industrial energy-saving technologies have been: coal-fired steam turbine cogeneration units, improved diesel engines, boiler workshops, irrigation systems, coil-coating ovens, computer-controlled ovens, high-temperature ceramic recuperators, and slow-speed diesel cogeneration units.[27]

EPACT specifically extends DOE's industrial RD&D responsibilities to pulp and paper production processes, electric drives, pollution-prevention technologies and processes, advanced manufacturing, and advanced materials. It also authorizes DOE to undertake joint ventures to help commercialize the technologies that it has supported.

Another federally-funded technology demonstration effort is the National Industrial Competitiveness through efficiency: Energy, Environment, and Economics (NICE^3) program. This grant program, administered by DOE and EPA, supports new technologies that can significantly reduce high-volume wastes, conserve energy, and improve cost-competitiveness in industry. It is designed to demonstrate the new processes and equipment, identify barriers to industrial pollution-prevention techniques, and develop and implement strategies to overcome these barriers. The costs of the demonstration projects are shared by industry, States, and the NICE^3 office. NICE^3 was funded at $1.4 million in FY 1992 by DOE and EPA.

EPA requested funding in 1993 to establish a pollution-prevention demonstration program called Waste Reduction Innovative Technology Evaluation (WRITE).[28] These demonstration projects will be carried out to encourage the transfer of technical information among industries.

NONUTILITY POWER GENERATION

Cogeneration, the simultaneous production of both electricity and steam, usually consumes less fuel than would be needed to produce both separately. Many companies that produce and use steam find it profitable to cogenerate and to sell any unneeded power. PURPA, enacted in 1978, encourages cogeneration by mandating that utilities purchase the excess electricity at rates set by the avoided cost of procuring additional power. Prior to PURPA, companies that sold cogenerated electricity to another user were subject to burdensome public utility regulations.

EPACT further encourages cogeneration by increasing electricity transmission access. This will enable cogenerators to sell their power to utilities offering prices higher than those of the local utility.

UTILITY EFFORTS ENCOURAGING INDUSTRIAL ENERGY EFFICIENCY

EPACT authorizes grants to be made to States that encourage their utilities to adopt Federal standards regarding IRP and DSM. The utilities must provide companies with process-oriented assessments and with financial incentives for implementing energy efficiency improvements. The Federal grants are for promoting the use of energy efficient technologies in industry, training individuals in conducting process-oriented industrial assessments, and assisting utilities in devel-

---

[27] Ibid.

[28] U.S. Environmental Protection Agency, *Fiscal Year 1993 Justification of Appropriation Estimates for Committee on Appropn"ations,* Report No. PM-225, 1992.

oping, testing, and evaluating industrial energy-efficiency technologies and programs.

The act also allows industrial customers to exclude part of the value of utility-provided, energy conservation subsidies from their gross income for tax purposes. This make the subsidies more powerful motivating tools, because companies can retain their full benefit.

H Goals

Energy issues have matured significantly during the last two decades. Early on, the goal of U.S. energy policy was confined to market security—keeping energy available and inexpensive. Policy dealt primarily with foreign petroleum dependence and regulation of the electricity and natural gas markets. Later, energy policy came to encompass two additional goals, environmental quality and economic competitiveness. Current and future energy policy interests include slowing the increase of oil imports, holding down energy costs, improving the international competitiveness of U.S. goods and services, and addressing environmental concerns of acid rain, urban ozone, and global warming.

Many studies by OTA and others have identified energy efficiency as a critical cornerstone to an energy policy framework that addresses these various issues. Even though this central role for energy conservation and efficiency has been identified, most of the Federal Government's energy efforts have focused on improving energy supplies. Only about 7 percent of DOE's nondefense appropriations are channeled toward conservation and efficiency activities.[29]

Energy efficiency can be raised through policies that prompt industry to conserve fossil fuels and electricity, to cogenerate electricity, and to reuse products and recycle materials. These same policies, plus those that induce industry to change the types of energy it uses (i.e., shifts among fossil fuels and from fossil fuels to electricity or renewable), can be used to reduce $C0_2$ emissions. In some instances, the policies can meet the objectives of economic vitality, environmental quality, and national security simultaneously. In other cases, proposals may -pursue conflicting goals. For example, increased reliance on coal could reduce oil import dependence, but exacerbate problems of air pollution and global climate change. It is necessary, therefore, to be clear about the role energy policy is to play in meeting these goals.

MARKET SECURITY

U.S. dependence on foreign supplies of petroleum has been a national security concern for decades. Curtailing industrial use of petroleum through conservation, fuel switching, and recycling are several means to enhance energy security.

Industry uses petroleum for two principal purposes, as a fuel for process heat and steam generation, and as a feedstock for petrochemicals, lubricants, solvents, waxes, and asphalt. Roughly the same amount of petroleum is used for each of these two purposes, but feedstock consumption appears to be growing, while fuel use seems to be remaining fairly steady. Reduction of fuel use is amenable to conservation and fuel-switching efforts. Feedstock use reduction, which is much less tractable by these strategies, is best approached through recycling of motor oil, plastics, and other petroleum-based products and through research to find suitable nonpetroleum substitutes.

ENVIRONMENTAL QUALITY

Air, land, and water degradation occurs at various points in the energy cycle. First, there are the problems associated with producing and transporting energy, and disposing of nonfuel energy products. Among the concerns are: oil spills; nuclear accidents; natural gas explosions; harmful electromagnetic fields; and land, river,

---

[29] Based on FY 1977 to 1991 data compiled by the Congressional Research Service. F. J. Sissine, Congressional Research Service, Library of Congress, *Energy Conservation: Technical Efficiency and Program Electiveness,* CRS Issue Brief IB85 130, Oct. 28, 1992.

and wildlife disturbances. Second, there are the air quality problems associated with the burning of fossil fuels. Here the concerns are acid rain, urban ozone, and $C0_2$ emissions.[30] Conservation, recycling, and fuel switching can play important roles in reducing both types of adverse environmental effects.

Energy conservation is the most straightforward of the strategies. It can alleviate environmental problems at all points in the energy cycle. Recycling can be used to mitigate problems with the disposal of nonfuel energy products. Fuel switching involves the most tradeoffs. In the area of energy production and transport, fuel switching merely substitutes one environmental problem for another. In the area of air quality, the goal of a fuel-switching strategy would be to shift from the dirtier, carbon-intensive fuels (e.g., coal and petroleum) toward the less intensive, cleaner energy sources (e.g., natural gas and renewable). One type of energy switching, electrification, requires special attention. Electricity is always cleaner than other energy forms at the point where it is used. However, it may or may not be cleaner from a wider perspective, because of inefficiencies involved in fossil fuel-based electricity generation.

ECONOMIC COMPETITIVENESS

U.S. industrial competitiveness depends on domestic companies holding down their production costs and improving the quality of their products. Energy efficiency improvements and energy price modifications can help boost competitiveness by reducing costs.

Companies can lower their costs by using efficient equipment, processes, and practices to conserve energy. In some cases, efficient technologies can have additional benefits, such as lower labor or environmental costs or better product quality.

Businesses can also reduce their costs by seeking out low-priced sources of energy. However, from a public policy perspective, enhancing industrial competitiveness by lowering or raising energy prices is particularly tricky. On the one hand, low energy prices translate directly into low energy costs. This helps competitiveness in the short term. On the other hand, high energy prices act indirectly to hold energy costs down by encouraging conservation and energy efficiency. This can advance competitiveness in the long run, if the costs can be successfully held in check through efficiency gains. High energy prices also *further* other goals of energy security and environmental quality.

MULTIPLE OBJECTIVES

Having multiple goals is itself an important aspect of energy policy. Linking the goals of energy security, environmental quality, and economic competitiveness gives great weight to energy policy in general and efficiency programs in particular. This positive characteristic is diminished somewhat, though, by the additional policy problems and constraints that come with multiple objectives. Program formulation is more challenging, because more criteria must be met. Program evaluation is more difficult, because there is no single measure of success. Moreover, the need for program coordination becomes vital. There must be good coordination among all of the programs and all of the decisionmakers in the relevant policy areas. This requires resolution of jurisdictional issues among congressional committees on energy, commerce, science, technology, environment, and finance. It also requires coordination and cooperation among executive agencies such as DOE, EPA, and the U.S. Department of Commerce. Without proper attention, these coordination challenges engender inaction.

---

[30] Note that feedstock uses of fossil fuels do not contribute to these air quality problems unless the products are later incinerated.

1 Issues

Industrial energy efficiency is enhanced by any cost-effective action, regardless of purpose, that reduces energy use per unit of output. The degree to which various policy options foster such actions in an equitable and effective manner turns on several fundamental controversial issues. For whom should the actions be cost-effective, the corporate energy user or society as a whole? Are there industrial inefficiencies that need to be corrected? Are industrial decisions always financially rational? What effects do energy prices have on efficiency?

COST-EFFECTIVE FOR WHOM?

The cost-effectiveness of a potential efficiency measure depends on which costs and benefits are considered. From the corporate perspective, the only relevant costs and benefits are those borne by the energy user. The costs include the expenditures for equipment, engineering, and installation as well as charges for production downtime. The benefits include the energy cost savings, plus any other net benefits, such as enhanced labor productivity, environmental compliance, or product quality, that accrue to the firm. These are the traditional accounting costs and benefits that directly affect the fro's bottom line. Basing policy on this narrow view of cost-effectiveness directly addresses the goal of economic competitiveness.

From a societal viewpoint, there is a wider range of relevant costs and benefits. All monetary, health, and ecological costs and benefits accrued to society are pertinent. Certain societal benefits, such as reduced local air pollution, diminished global warming, and avoided military conflicts over oil supplies, are very controversial. They are external to the markets and are very difficult to quantify. Moreover, they accrue to society at large, not to the particular party implementing the efficiency measure. This wider definition of cost-effectiveness is the more important measure for policy aimed at energy security and environmental quality. ,

Energy efficiency measures generally appear more cost-effective from the societal perspective than from the corporate view. This happens because more benefits are accounted for in the societal perspective. Consequently, environmental advocates and others taking the societal view are usually more optimistic than those with the corporate view about the potential energy savings that can be cost-effectively achieved.

This report adopts the traditional, more widely accepted, corporate perspective of cost-effectiveness. This view is chosen not to dismiss the value of societal costs and benefits but to examine where traditional market forces lead.

IS INDUSTRY ALREADY ECONOMICALLY EFFICIENT?

Analysts dispute the existence of significant cost-effective energy savings in industry. Some argue that companies minimize their costs by undertaking all cost-effective improvements and are, therefore, already as efficient as the market demands. A corollary is that all managers make rational, cost-minimizing, decisions. In this view, unimplemented energy savings must by definition not be cost-effective. Analysts that find industry already economically efficient believe that additional energy savings will be expensive and harmful to competitiveness.

The counterargument is that companies do not minimize their total costs in practice and are, therefore, not economically efficient. Many cost-effective energy savings are not pursued because of lack of information on relevant technologies, capital constraints caused by budgeting methods, inattention to energy issues, and general aversion to change. This behavior ultimately arises from disparate goals of management and stockholders, managers' personalities as they relate to external competitive pressures, managerial inertia, and organizational entropy. Analysts that take this view are generally more optimistic about the level of cost-effective energy savings that can be achieved.

WHAT ROLE DO ENERGY PRICES PLAY?

The influence of energy prices on industrial energy use is another disputed topic. Macroeconomic theory holds that prices should have a strong effect on energy use. Increases in energy prices lead to improved energy efficiency, because they raise the cost-effectiveness of implementing energy-saving technologies and processes. Price rises also lead companies to look for alternative energy sources through least-cost supply procurement, fuel switching, and cogeneration. In extreme cases, they may prompt companies to migrate to regions where prices are lower. These effects are more pronounced for the more energy-intensive companies and industries.

Several studies have examined the extent to which price effects are reflected in historical energy-use patterns. Typically, they compare the energy-intensity trends of the oil embargo period from 1973 to the early 1980s with those of earlier periods. Differences in the trends can be attributed to some degree to the high prices that existed during the oil embargo period. The data presented in figure 1-1 show that overall energy intensity declined more quickly during the high-price period than it did in earlier periods. This data is not conclusive, however, because it includes the effects of both efficiency improvements and structural changes. Analysts who have examined the efficiency and structural components of the energy intensity trends in this period disagree about the influence of the oil embargo period, Some have shown that efficiency (real-energy intensity) improved faster after the 1974 oil embargo than before it.[31] Others have suggested that efficiency improved steadily from 1958 to 1985, and that the energy shocks of the 1970s did not significantly accelerate the improvement.[32] The disparity appears to stem in large part from differences in the measures of industrial output that are used in the calculations.

Understanding the relationship between energy prices and industrial energy use is very important for assessing the effects of price-related policy initiatives. It holds the key to estimating how various energy and carbon-tax proposals would affect industry's energy use and carbon emissions.

POLICY OPTIONS

Strategies

Crafting policies to enhance energy efficiency is more challenging for industry than for other sectors of the economy. The greater difficulty arises from the diversity of industrial energy use—there are thousands of industrial processes each having unique energy characteristics-and from the interconnections between energy and production costs, product quality, environmental compliance, and other sensitive business factors. Several points are clear, however. First, energy efficiency is best promoted through policies that: 1) increase investment in industrial plants, and 2) focus that investment in a manner that encourages adoption of efficient technologies and production methods. Second, the energy conservation and efficiency activities and investments should be consistent with sound business strategy. Energy taxes or mandated investments that are too costly can put domestic companies at a competitive disadvantage, unless the costs are offset by import tariffs, export subsidies, or commensurate cost increases for foreign firms. Third, the relevant technical objectives for policy include: increasing the use of energy-conserving equipment, processes, and practices; spreading the practice of electricity cogeneration; expanding the reuse of products and recycling of materials; and decreasing the carbon-intensity of the industrial energy mix through fuel switching or electrification.

---

[31] G. Boyd et al., op. Cit., footnote 3.

[32] R.B. Howarth, "Energy Use in U.S. Manufacturing: The Impacts of the Energy Shocks on Sectoral Output, Industry Structure, and Energy Intensity," *The Journal of Energy and Development,* vol. 14, No. 2, pp. 175-190, 1991.

The first major objective-increasing investment in industrial plants-depends on a healthy business and financial climate. The business environment must include both economic growth and competition to compel investment. Without market growth, corporations have neither the resources nor the incentive to invest. Without competition, companies are under little pressure to invest, If companies' profits are secure, there is little need for them to invest in plants and equipment. Competition that is vigorous but fair signals to companies that being profitable depends on being efficient. The financial environment must include low capital costs and a long-term outlook, both of which depend on interest rates and tax codes, to encourage investment in industrial plants. In the United States, high capital costs and stock-market pressures favor short-term profits over long-term investment. OTA examined how macroeconomic policies affect the business and financial climate in an earlier report.[33]

The second major objective for improved energy use is that efficient technologies and production methods are implemented when investment occurs. Efficient technologies that are both cost-effective and reliable must exist and be available at the time of investment. Also, they must be given adequate consideration in investment decisions. Investments can be focused to advance the various technical objectives—conservation, cogeneration, recycling, and energy shifting-through financial incentives, regulations, information programs, and technology RD&D (table l-l).

These policy options vary widely in their energy savings and their costs to the government, businesses, and consumers. To illustrate the range of effects, the specific options are grouped into three distinct levels, in order of increasing Federal involvement and energy savings. The *basic* level includes relatively low-cost, simple policy options that require little or no new legislation or change from present practice. If Congress determines that changes are needed to effect improvements in energy efficiency, then the basic level could be considered as a first step. The *moderate* level includes several options that are more ambitious and in many cases would require modifying existing legislation and increasing Federal spending. The *aggressive* level includes options that are quite ambitious, would require new legislation, or would require an increased Federal role in energy regulation; the options on this level would require additional funding.

1 Information Programs

The general lack of concern afforded energy in many corporations is a major barrier to investment in energy efficiency improvements. This problem can be addressed through policies that raise the profile of energy efficiency as a national and corporate goal. The Federal Government could assist by providing technical assistance, supporting education and advertising programs, and establishing equipment-labeling requirements.

TECHNICAL ASSISTANCE

Many companies, especially smaller ones, are unaware of many of the ways they could improve their energy efficiency. Energy audits and training programs can help companies recognize opportunities for improving their energy efficiency. Many utilities provide audits to companies in their service territories. In addition, the Federal Government currently provides low-cost

---

[33] U.S. Congress, Office of Technology Assessment, *Making Things Better: Competing in Manufacturing*, OTA-ITE-443 (Washington, DC: U.S. Government Printing Office, March 1990). Among the options suggested by this report to improve the financial environment were: decreasing the Federal budget deficit; granting inducements for increased personal and business savings; extending tax inducements (credits and accelerated depreciation) for technology development and capital investment; providing incentives for investors to hold investments longer; and increasing the stability and predictability of the financial and political environment.

Table 1-1—Policy Options for Improving Industrial Energy Efficiency

		Conservation of fossil fuels	Conservation of electricity	Cogeneration	Fuel switching and electrification[a]	Level of Federal involvement and energy savings
Information programs						
Technical assistance	Expand government-supported auditing and diagnostic assistance to small-and medium-sized industrial plants.	X	X	X	X	Basic
	Develop training and certification programs for energy managers and auditors.	X	X	X	—	Basic
	Continue assistance to electric utilities with industrial DSM program design.	—	X	—	X	Basic
	Offer assistance to natural gas utilities with industrial DSM program design.	X	—	—	X	Basic
Education and advertising	Promote energy-conserving technologies through workshops and technical literature.	X	X	X	X	Basic
	Expand public recognition program for corporate commitments to efficiency (such as Green Lights program).	X	X	—	—	Basic
Equipment labeling	Study effectiveness of implementing energy-efficiency labeling program for generic industrial equipment such as pumps, fans, compressors, and boilers.	X	X	—	—	Basic
Financial incentives						
Loan assistance	Guarantee loans and/or subsidize interest rates for energy efficiency investments.	X	X	X	X	Moderate
Investor income tax provisions	Grant tax-free status to dividends earned on bonds used to finance energy efficiency investments.	X	X	X	X	Moderate
Energy and carbon taxes	Research effects of taxation on industrial competitiveness and viability of methods, such as export rebates, for mitigating competitive harm.	X	X	X	X	Basic
	Tax fossil fuel use • fuel specific (e.g., petroleum) • based on heat or carbon content of fuels.	X	X	X	X	Moderate or aggressive
	Tax imports of petroleum.	X	—	—	X	Moderate or aggressive
	Tax CO_2 emissions • from industrial processes • exempt cogeneration units.	X	—	X	X	Moderate or aggressive
Corporate income tax provisions	Grant tax credits and/or accelerated depreciation for efficiency investments.	X	X	X	X	Moderate

Regulations						
Efficiency standards	Study effectiveness of implementing energy efficiency standards for generic industrial equipment such as pumps, fans, compressors, and boilers.	X	X	—	—	Basic
Utility oversight	Provide incentives to State utility regulatory commissions for encouraging natural gas utilities to adopt aggressive industrial DSM programs.	X	—	—	—	[illegible]
	Further relax electricity-transmission rules to allow sales/transfers of cogenerated power directly to other industrial plants.	—	—	X	—	Moderate
Reporting and targeting	Establish government-run efficiency reporting and targeting programs.	X	X	—	—	Moderate
Environmental permits	Require permits for CO_2 emissions • from industrial processes • exempt cogeneration units.	X	—	X	X	Aggressive
Research, development an demonstration	Expand technology demonstration efforts.	X	X	X	X	[illegible]
	Expand efforts to improve energy efficiency of industrial equipment and processes.	X	X	—	X	[illegible]
	Support efforts to develop alternative, nonfossil, feedstock materials for plastics and fertilizers.	X	—	—	—	Moderate

[a] Shifts in the energy mix: from high-carbon to low-carbon fossil fuels, and from fossil fuels to electricity or renewable energy sources.

KEY: DSM = demand-side management; CO_2 = carbon dioxide.

SOURCE: Office of Technology Assessment, 1993.

audits to small and medium-sized companies. This program is small, but very cost-effective. The government could enhance these efforts by opening additional Energy Analysis and Diagnostic Centers and Manufacturing Technology Centers, and by developing training and certification programs for energy managers and auditors.

Many energy utilities have instituted IRP and DSM programs. These programs raise energy awareness and assist in identifying and funding energy-saving investments. However, relatively few of these programs are aimed at industrial consumers. The Federal Government, in providing technical assistance to utilities, could expand its efforts in the area of industry program design and monitoring.

EDUCATION AND ADVERTISING

The Federal Government could raise energy awareness by providing information on energy efficient technologies through technical literature, workshops, and meetings. EPA could continue to expand its voluntary energy-conservation programs (e.g., Green Lights) to include more types of equipment. The government could also actively recognize companies and industries that have made large energy efficiency gains; for example, those that have met or surpassed their voluntary efficiency targets or have kept their conservation commitments to EPA.

EQUIPMENT LABELING

Product labeling makes information about equipment-performance characteristics, such as energy consumption and operating costs, easily available. Labels assist equipment purchasers in making informed decisions, while increasing the attention paid to energy use. Labels are especially useful for small items, which are often purchased without much study. EPACT contains provisions for labeling electric motors. Congress could request DOE to examine the effectiveness of labeling other generic equipment such as pumps, fans, compressors, and small boilers.

H Financial Incentives

Financial measures can be used to alter investment patterns in order to promote the various technical objectives. These policy instruments include loan assistance, revisions to the income tax code, and taxation of energy consumption or CO2 emissions.

LOAN ASSISTANCE

In many companies, lack of funds constrains investment. A loan pool with funds earmarked for energy-saving projects could be used to increase efficiency investment. The pool could be financed from a combination of Federal, State, and utility sources. lending could occur under a variety of terms. Interest terms could be set at market, or perhaps below-market, rates, To ensure good faith, companies could be required to put up matching finds or agree to undertake a minimum investment in efficiency.

INVESTOR INCOME TAX PROVISIONS

Investment funds could also come from private sources by making dividends earned on bonds floated for energy efficiency projects tax-free. This would increase the pool of low-cost capital available for these projects. Such funds might be used to assist companies that have limited access to capital or have little use for tax credits because of profitability problems.

ENERGY AND CARBON TAXES

Energy prices, despite their disputed effects on energy efficiency trends, can be an important factor in investment decisions. They are a major influence on energy-focused investments and a lesser factor in general investment projects. By increasing energy prices, energy or carbon taxes raise the attention paid to energy use and spur implementation of energy-saving technologies and processes by increasing their cost-effectiveness.[34] They also lead companies to look for alternative energy sources such as cogeneration, fuel switching, and least-cost supply procurement. The energy effects, however, have been secondary to the issues of revenue generation and burden equitability in the public debate about such taxes.

Several different energy and carbon taxes have been proposed. Some are broad-based taxes, which would be levied on the Btu value, sales value, or carbon content of all energy sources.[35] Others are more fuel-specific taxes. These include taxes on gasoline and tariffs that establish a price floor on oil imports, meant to address issues of petroleum use, production, and importation. President Clinton's Btu tax proposal and foreign energy taxes and prices are discussed in box l-D.

The various energy and carbon taxes would affect the fuels used by industry in different ways. The Btu tax and carbon taxes would (if assessed at the same rate on all fuels) fall heaviest on coal, because its price per Btu and per carbon content is the lowest. Natural gas would be favored over residual oil under a carbon tax, while the opposite would be true under a Btu tax. A sales (ad valorem) tax would affect all fuels equally. It should be noted that applying energy and carbon taxes to petroleum-based feedstock materials would do little to reduce CO2 emissions at industrial production facilities. Such materials are not burned at these sites. They are, however, sometimes burned as post consumer waste at incinerators. Taxes on virgin feedstocks would encourage plastics recycling, rather than burning, thus reducing CO2 emissions.

The Congressional Budget Office (CBO) has estimated that a tax of $100 per ton of carbon would reduce overall energy consumption in the industrial and commercial sectors by 6 to 8 percent below current levels by 2000.[36] However, the costs could be quite high, both to companies and to the economy as a whole. CBO estimated that the tax would lower the annual gross national product (GNP) by about 0.5 to 2.0 percent ($40 to $130 billion) below what it would be otherwise by the end of the frost decade, and that the effects could be 5 percent or more in the frost few years of a suddenly instituted tax.

The costs would depend on revenue disposition as well as the tax rate. DOE estimated that a $1 per million Btu tax instituted in 1991 would decrease GNP in 2000 by 0.7 percent ($39 billion) if the revenues were used for deficit reduction.[37] The GNP decrease was estimated to be 0.6 percent ($35 billion) if the revenues were offset by a reduction in payroll taxes and the deficit was not reduced, the deficit neutral case.[38] A study by the American Council for an Energy-Efficient Economy (ACEEE) estimates that with an energy tax that generates $25 to $30 billion in Federal revenues, total U.S. energy expenditures could decrease over the coming decade if 15 percent of

---

[34] Energy price controls are another policy tool that can be used to encourage conservation and fuel switching. They have been employed during inflationary periods, but are rarely considered today.

[35] The environmental intent of carbon taxes would be to tax CO_2 emissions, but the tax would probably be levied on fuels at the point of purchase for convenience reasons, This is justified because nearly all of the carbon in fossil fuels is emitted into the atmosphere when the fuels are burned. There are no viable $C0_2$ scrubbers or other carbon fining technologies to prevent release into the atmosphere. The higher carbon fuels, such as coal, would be taxed heavier than the lower carbon fuels, such as natural gas.

[36] U.S. Congress, Congressional Budget Office, *Carbon Charges as a Response to Global Warming: The Effects of Taxing Fossil Fuels* (Washington DC: U.S. Government Printing Office, August 1990).

[37] U.S. Department of Energy, Energy Information Administration, *Studies of Energy Trees*, SR/EMEU/91-02, 1991.

[38] DOE made similar estimates for a $45/ton carbon tax, which would generate roughly the same Federal revenues as a $1/million Btu tax. The carbon tax was estimated to decrease GNP by 0.8 percent ($43 billion) in the deficit reduction case and by 0.7 percent ($38 billion) in the deficit neutral case.

Box I-D—Energy Taxes

Clinton Btu Tax Proposal

In February 1993, President Clinton announced plans for instituting an energy tax as part of his economic revitalization program, ***A Vision of Change for America.*** The proposed energy tax would be levied at the rate of $0.599 per million Btu for petroleum products and at $0.257 per million Btu for most other fuels. Electricity generated from nuclear and hydro sources would be taxed at their input Btu rates, Energy materials used as feedstocks would be exempted from the tax. The tax would be phased in over 3 years and would be indexed to inflation beginning in the fourth year.

The following table shows the proposed assessment rates for various fuels. The actual price increases caused by these taxes would depend on their energy supply and demand effects in addition to their assessed rates.

Fuel	Ciinton proposal ($)	Percent of price	industrial prices 1991 ($)
Natural gas	**$.27/mcf**	10.3%	$2.63/mcf
Light fuel oil	**.08/gallon**	**11.4**	**.70/gallon**
Heavy fuel oil	**.09/gallon**	**30.0**	**.30/gallon**
Coal (steam)	**5.66/ton**	**16.9**	**33.51/ton**
Electricity (fossil or hydro)	**.003/kwh**	**6.1**	**.049/kwh**
Electricity (nuclear)	**.004/IM/h**	**8.2**	**.049/kwh**

Foreign Taxes

The overall rate of current energy taxation in the United States is difficult to determine because energy is taxed differently in each State. However, energy taxes are probably lower in the United States than in other industrialized nations. Regardless of the actual rates, U.S. energy taxes are not great enough to raise industrial energy prices above those of other highly industrialized countries. On average, U.S. industry pays lower energy prices than its major foreign competitors, except in the case of natural gas and electricity in Canada. Complete data on industrial ***energy prices*** in developing countries, some ***of*** which are major competitors in energy-intensive industries, are not available to make a similar comparison for all U.S. competitors.

	United States	Japan	Germany	France	United Kingdom	Canada
Tax (1991)						
Natural gas ($/m@...	**NA**	**.32**	**.56**	**0**	**0**	**0**
Light fuel oil ($/gallon)	0	**.03**	**.16**	**NA**	**.09**	**0**
Heavy fuel oil ($/gallon)	**0**	**.02**	**.06**	**.08**	**.06**	**0**
Coal (steam) ($/ton)	**NA**	**1.84**	**0**	**0**	**0**	**NA**
Electricity ($/kWh)	**NA**	**.008**	**.007**	**0**	**0**	**NA**
Price (including tax) 1991						
Natural gas ($/mcf)..	**2.63**	**11.04**	**5.23**	**3.94**	**4.19**	**2.26**
Light fuel oil ($/gallon)	**.70**	1.02	**1.02**	**NA**	**.84**	**.72**
Heavy fuel oil ($/gallon)	.30	.86	.49	.41	.44	.37
Coal (steam) ($/ton)	33 .51	63.29	165.49	91.84	69.82	54.92
Coal (metallurgical) ($/ton)	48.83	56.10	56.45	58.32	**NA**	**51.60**
Electricity ($/kWh)	**.049**	**.136**	.088	.054	.071	.039

NOTE: **Coal prices for Canada are for 1989.**

SOURCES: Office of the President, *A Vsion of* Change for America (Washington, DC: 1993). International Energy Agency, *Energy Prices and Taxes, Third Quarter 1992.*

the energy tax revenues were recycled into energy efficiency programs.[39]

Energy-intensive industries would be hit particularly hard by the levying of energy or carbon taxes. In these industries, energy prices play a large role in the competitiveness among nations. Taxes could damage these industries' competitiveness and could lead to migration of production facilities to offshore regions where energy prices are low. This could be countered by border adjustments, such as duties on imports containing large amounts of embedded fossil energy (with offsets for any nonrefunded energy taxes paid in the exporting country) and rebates for exports of such products.

Most economists prefer taxes over other policy tools as the means for encouraging greater energy efficiency. Taxes send clear economic signals and allow varied technical approaches to achieving goals. Moreover, they can be rationalized as the transference of some of energy's external costs from society as a whole to energy users themselves.

CORPORATE INCOME TAX PROVISIONS

The corporate income tax code can be used to make energy-conserving investments appear more cost-effective to corporate decisionmakers. Granting tax credits, accelerated depreciation, or other tax-reducing devices to energy efficiency expenditures would increase the financial attractiveness of these investments. The benefits of such tax provisions would have to be weighed against the lost revenues to the Treasury.

From 1978 until 1985, a 10 percent tax credit was in effect for investments in: 1) specified equipment, such as boilers that use coal or alternative fuels; 2) heat conservation equipment; and 3) recycling equipment.[40] These tax credits have been found by OTA and other researchers to have little effect on corporate investment decisions.[41] Credits were taken for eligible projects, but they rarely caused a company to implement one technology rather than another. They did little to shift companies' perceptions of the cost-effectiveness of various technologies. These credits have also been criticized for specifying technologies, thus discouraging the use of new technologies and concepts.

If tax credits were tried again, the rates would have to be considerably higher and the list of eligible conservation technologies would have to be greatly expanded in order to significantly alter investment patterns. Credits could also be applied to process-oriented RD&D expenditures. It is important to recognize, however, that credits can influence companies' investment only in profitable years. They do little in unprofitable years when no taxes are paid.

Accelerated depreciation schedules can also be used to facilitate investments that improve energy efficiency. Shortening the depreciation period for conservation investments could improve their cost-effectiveness.

I Regulations

Regulations are the most direct method of changing industrial behavior. Among the most

---

[39] H. Geller, J. DeCicco, and S. Nadel, Structuring *an Energy Tax So That Energy Bills Do Not Increase* (Washington, DC: American Council for an Energy-Efficient Economy, 1991).

[40] The tax credits were enacted as part of the Energy Tax Act of 1978, Public Law 95-618 and expanded by the Crude Oil Windfall Profits Tax Act, Public Law 96-223. The eligible heat conservation equipment (specially defined energy property) included recuperators, heat wheels, regenerators, heat exchangers, waste heat boilers, heat pipes, automatic energy-control systems, turbulators, preheater, combustible gas-recovery systems, economizers, and modifications to alumina electrolytic cells. In addition, the law denied tax credits for the installation of oil- and gas-fired boilers and granted rapid depreciation allowances for their early retirement. Proposals were made, but never enacted, to extend the credits to industrial insulation industrial heat pumps; modifications to burners, combustion systems, or process furnaces; batch operations conversion equipment; product separation and dewatering equipment; and fluid-bed driers and calciners.

[41] OTA, op. cit., footnote 8. Alliance to Save Energy, *Industrial Investment in Energy Efficiency: Opportunities, Management Practices, and Tax Incentives,* July 1983.

viable regulatory options for influencing industry's use of energy are equipment efficiency standards, pollution permits, reporting and targeting requirements, and utility oversight.

EFFICIENCY STANDARDS

Efficiency standards can be used to raise the average energy efficiency of certain types of industrial equipment. Excluding substandard equipment from the market limits purchasing options to higher efficiency equipment. Thus, average energy efficiency rises in the normal course of equipment turnover. Because higher efficiency equipment is costlier than standard equipment, efficiency standards exact an initial financial penalty on equipment buyers. However, this initial penalty is usually more than offset by the cost savings over the life of the equipment. Furthermore, efficiency standards act to lower the purchase prices of higher efficiency equipment by increasing the size of its markets.

Standards make sense only for new or replacement equipment, not for existing equipment. Upgrading all existing equipment to meet standards would be extremely expensive and difficult to manage.

Further, most industrial equipment is not amenable to standards, because of the diversity in the types of equipment and the operating environments. There are, however, some generic types of equipment that are amenable to standards. EPACT contains provisions for standards on new electric motors. Congress might request DOE to examine the practicality and effectiveness of efficiency standards for other generic equipment, such as pumps, fans, compressors, boilers, cogenerators, and rewound motors.[42]

UTILITY OVERSIGHT

Utilities, through their DSM efforts, can be a great source of information and funding for energy efficient technologies. Currently, most DSM programs are operated by electric utilities. Under EPACT, the Federal Government can offer financial incentives to States to pressure their PUCs and utilities to more aggressively pursue DSM. Further incentives or technical assistance could be provided to expand the DSM efforts of natural gas utilities.

REPORTING AND TARGETING

Requiring companies to periodically report on their energy consumption draws their attention to the importance of energy efficiency. The reporting also provides government with data that it needs to plan its various industrial energy programs. Setting energy efficiency targets for industries adds still more pressure for improvement. EPACT specified that DOE's current reporting program, the Manufacturing Energy Consumption Survey, be conducted at least every 2 years. The act also provided incentives for voluntary targeting programs to be established within trade associations. If the targeting programs do not gain wide acceptance, then Congress might consider establishing a government-based program in which the targeting would be mandatory.

ENVIRONMENTAL PERMITS

Companies could be required to obtain permits for their CO2 emissions. Limiting the number of available permits, perhaps to a set percentage of 1990 emissions, would encourage conservation and fuel switching. Under this system, companies would be free to choose the most cost-effective strategy for curtailing their $C0_2$ emissions. They could implement energy efficient technologies, fuel switching, or possibly some other emissions-cutting technique. Making the permits marketable would further enhance companies' options. Firms could trade their unused carbon permits to other

---

[42] DOE studied pump standards in the late 1970s. It did not recommend them, but a revisit of the issue may be in order.

firms whose emissions exceed permit levels, thereby creating a market for carbon emissions.[43]

EPACT calls for DOE to establish a voluntary reporting system to track greenhouse-gas emissions. This emissions baseline will help make permit allocations more equitable. Basing allocations on a long period of prior emissions reduces the disincentives for companies to make emissions cuts before the program begins.

Marketable permits are the basis of the U.S. regulatory approach for phasing out emissions of chlorofluorocarbon compounds (CFCs) and for reducing sulfur dioxide emissions to control acid rain. Marketable carbon permits are likely to be more difficult to implement than permits for CFCs or sulfur dioxide; nevertheless, such a system may still be less intrusive to firms than mandated emissions standards or technology standards. Use of marketable permits would entail a great amount of data collection and monitoring of industrial plants.

Other environmental policies that target air and water emissions, recycling, and hazardous and nonhazardous waste disposal also affect industrial energy use. Environmental directives are a very powerful tool in this regard, because energy-consuming technologies and processes tend to be major sources of pollution.

The cost to industry of environmental regulation is a major policy consideration in this area. If the costs are too onerous, industrial competitiveness can be severely impaired.

Research, Development, and Demonstration

Continuous improvement in energy efficiency requires a constant flow of advanced, commercially available technologies, which in turn requires a sustained RD&D effort. The Federal Government already supports this effort through the industrial energy conservation and efficiency RD&D program at DOE. Greater gains could be achieved by expanding the program and increasing the efforts to understand and overcome technology implementation hurdles. DOE's RD&D efforts should continue to stress technologies that achieve multiple goals. Technologies and processes that combine energy efficiency with more prominent corporate goals (e.g., product quality, labor productivity, or environmental compliance) generally have greater cost-effectiveness and are more likely to be adopted in industrial facilities.

Product Reuse and Materials Recycling

Product reuse and materials recycling have received considerable attention because of their role in reducing the need for additional landfills. A less publicized benefit is that reuse and recycling conserve energy.[44] For energy-intensive products, reusing them (e.g., refilling beverage bottles and copier cartridges) or producing them from recycled materials (e.g., reprocessed steel, aluminum, plastics, and paper) usually consumes less energy than producing them from virgin materials. There are many options for policies that would increase product reuse and materials recycling. The following options are mentioned for illustrative purposes:

- Resource subsidies, such as mineral depletion allowances and U.S. Forest Service below-cost timber sales, currently favor the use of virgin materials. These subsidies could be reduced or eliminated to promote the use of recycled materials. To ensure fair trade, goods containing virgin materials

---

[43] U.S. Congress, Office of Technology Assessment, *Changing by Degrees, Steps to Reduce Greenhouse Gases,* OTA-O-482 (Washington, DC: U.S. Government Printing Office, February 1991).

[44] OTA has considered these issues at length in other reports. U.S. Congress, Office of Technology Assessment, *Green Products by Design: Choices for a Cleaner Environment,* OTA-E-541 (Washington DC: U.S. Government Printing Office, October 1992); *Managing Industrial Solid Wastes From Manufacturing, Mining, Oil and Gas Production, and Utility Coal Combustion-Background Paper,* OTA-BP-O-82 (February 1992); *Facing America's Trash: What Next for Municipal Solid Waste?* OTA-O-424 (October 1989); and *Materials and Energy From Municipal Waste,* OTA-M-93 (July 1979).

would need to be subject to duties when imported and granted rebates when exported.

- Grants and technical assistance could be offered to help States and municipalities establish recycling programs.
- Government procurement programs could promote product reuse and materials recycling. By requiring a minimum recycled and recyclable content in certain of the products it buys, the government could foster the markets for recycled materials.
- Grants and technical assistance could be given for the development and implementation of a plastics identification system that would facilitate plastics recycling,
- Funding could be given for RD&D efforts to improve the viability of scrap-processing equipment and the quality of recycled materials.
- A Federal deposit-refund system for beverage containers, automobiles, and other recyclable products could be established.
- Manufacturers, wholesalers, and retailers could be required to collect and recycle the packaging used to deliver their products to market. The program could be extended to require that businesses collect and recycle their own products when discarded. A model for this might be Germany's nationwide packaging take-back program.

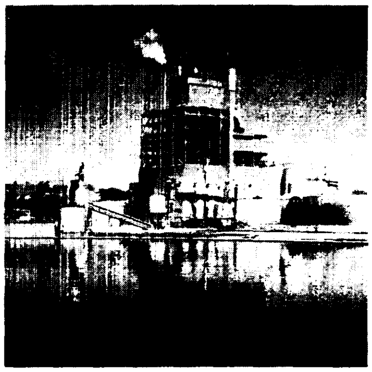
Industrial Energy Consumption

2

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

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

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



OVERALL ENERGY CONSUMPTION

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

---

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

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

Box 2-A—Energy Consumption Categories

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

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

The particular measure which is most important depends on the issues being examined. For example, carbon dioxide (CO2) emissions are tied to the fuels, both purchased and byproduct, that are burned at the plant and the electric utility. Feedstocks and other energy material inputs have little affect on $C0_2$ emissions. Energy security is sensitive to imported energy, whether used for heat, power, and electricity generation or for feedstocks. Competitiveness is dependent on purchased energy and byproduct energy. In general, use of purchased energy hurts competitiveness and use of byproduct energy helps.

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

SOURCE: Office of Technology Assessment, 1993.

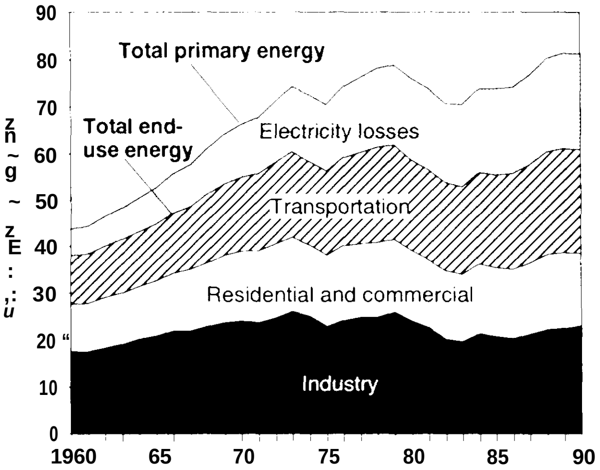
allocated to the electric utility sector, 38 percent—if the losses are allocated to the sectors using the electricity, and 39 percent-if the losses are disregarded altogether.

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

---

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

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



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

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

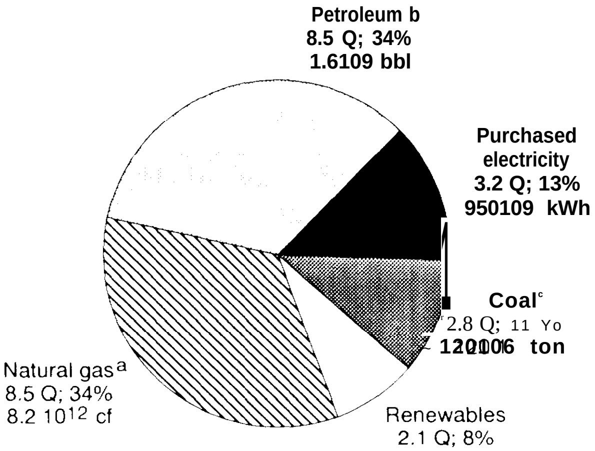
ENERGY SOURCES

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

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

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

Total: 25.0 quads



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

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

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

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

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

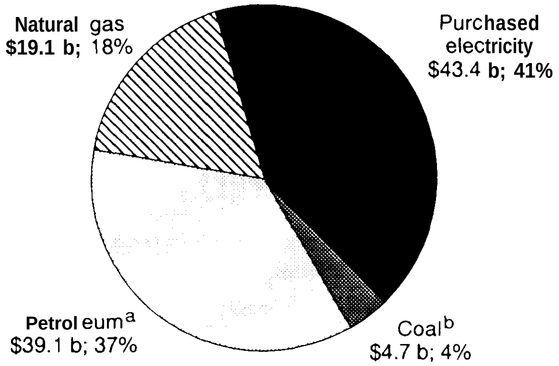
---

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

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

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

Total: $106 billion



a petroleum: distillate fuel oil $6.7 b; residual fuel oil $1.1 b; gasoline $1.7 b; LPG $8.5 b; asphalt and road oil $3.5 b; lubricants $8.0 b; other $9.6 b.

b Coal:steam coal $2.8 b, and metallurgical coal $1.9 b.

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

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

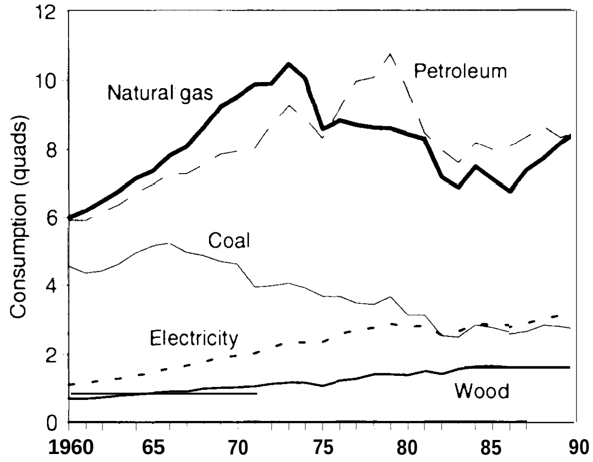
The mix of industrial energy sources has shifted during the last three decades (figure 2-4). Natural gas and petroleum have alternated as the most used industrial energy source. Natural gas was the largest energy source until the mid- 1970s. Use of natural gas began declining in 1974, because of supply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

I Prices

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

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

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



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

---

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

Table 2-1—Sectoral Energy Prices, 1990

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

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

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

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

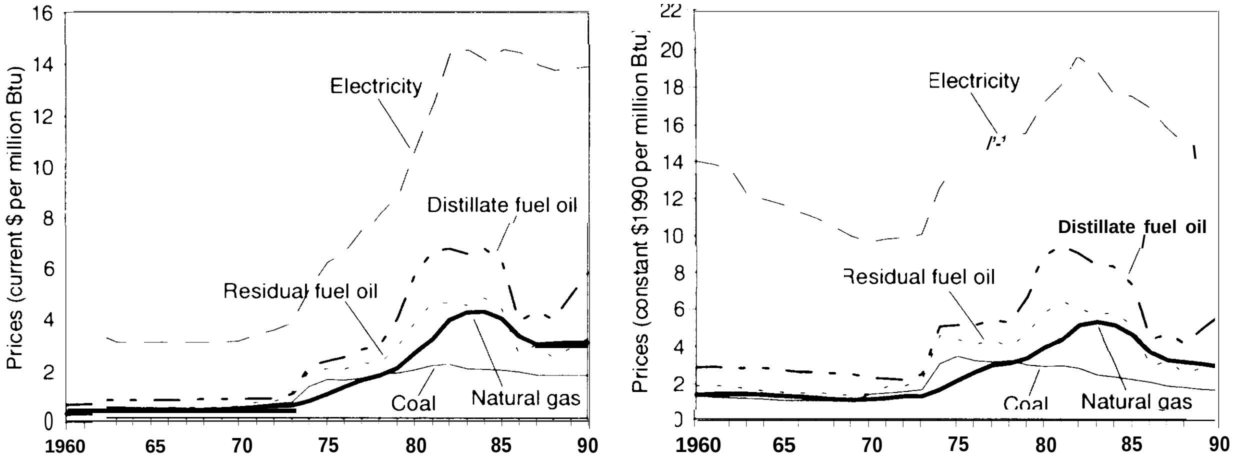
Industrial energy prices were stable until the 1974 oil shock and then rose until the early -1980s (figure 2-5). Since then fuel oil prices have fallen sharply, natural gas prices have declined moderately, and electricity and coal prices have remained stable. In real terms, prices after 1973 quadrupled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

H Electrification

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

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

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



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

I Fuel Switching Potential

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

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

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

I Cogeneration

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

---

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

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

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

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

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

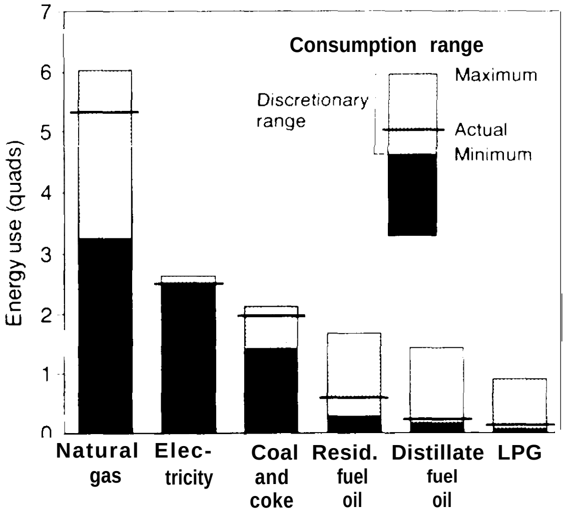
NOTE: Data are for the manufacturing sector only. Agriculture, forestry, fishing, mining, and construction are not included. Actual consumption is energy for heat, power, and electricity generation. Electricity consumption is off-site produced energy. Sum of alternative fuels does not equal potential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

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

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

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

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



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

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

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

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

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

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

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

I Functional Use

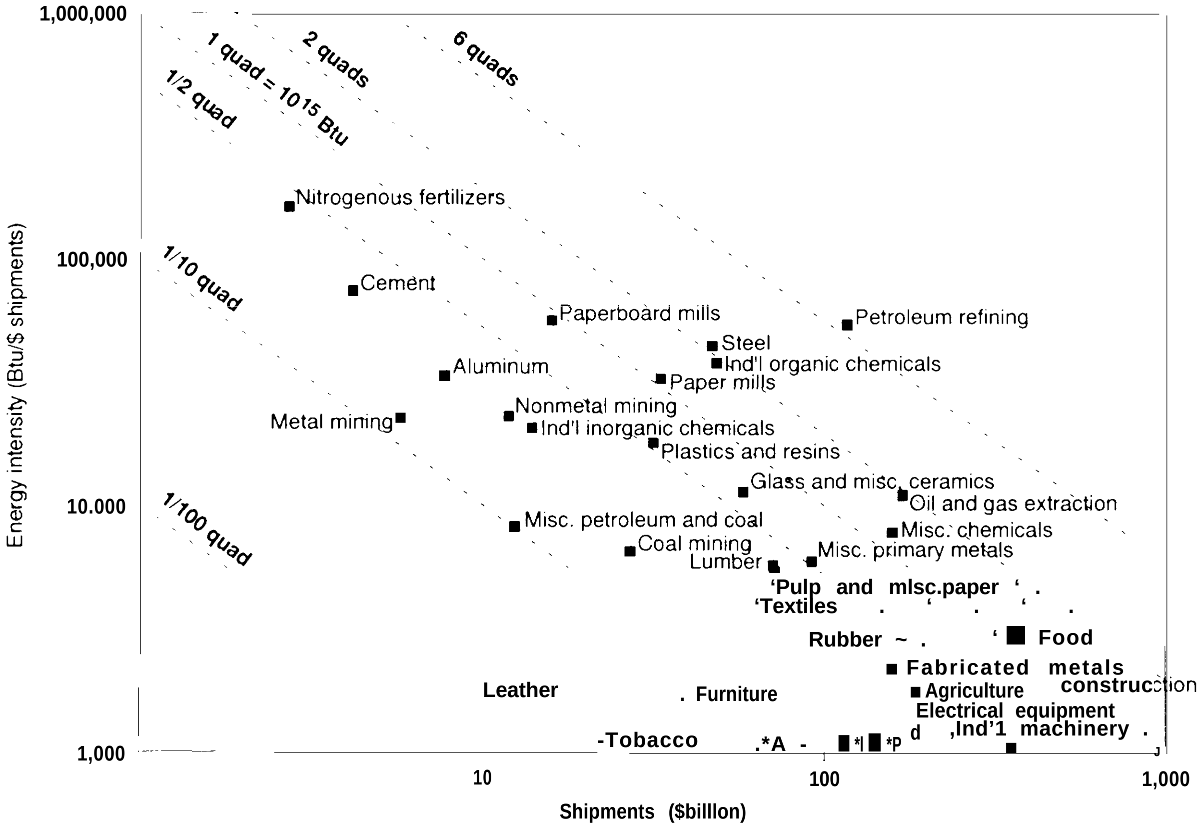
Industry uses energy for a variety of purposes. Steam production via conventional boilers and cogenerators is the largest use (table 2-3). It is fueled in most industries by fossil fuels, primarily natural gas. The principal fuels for steam production in the pulp and paper industry are wood and black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

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

---

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

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



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

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

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

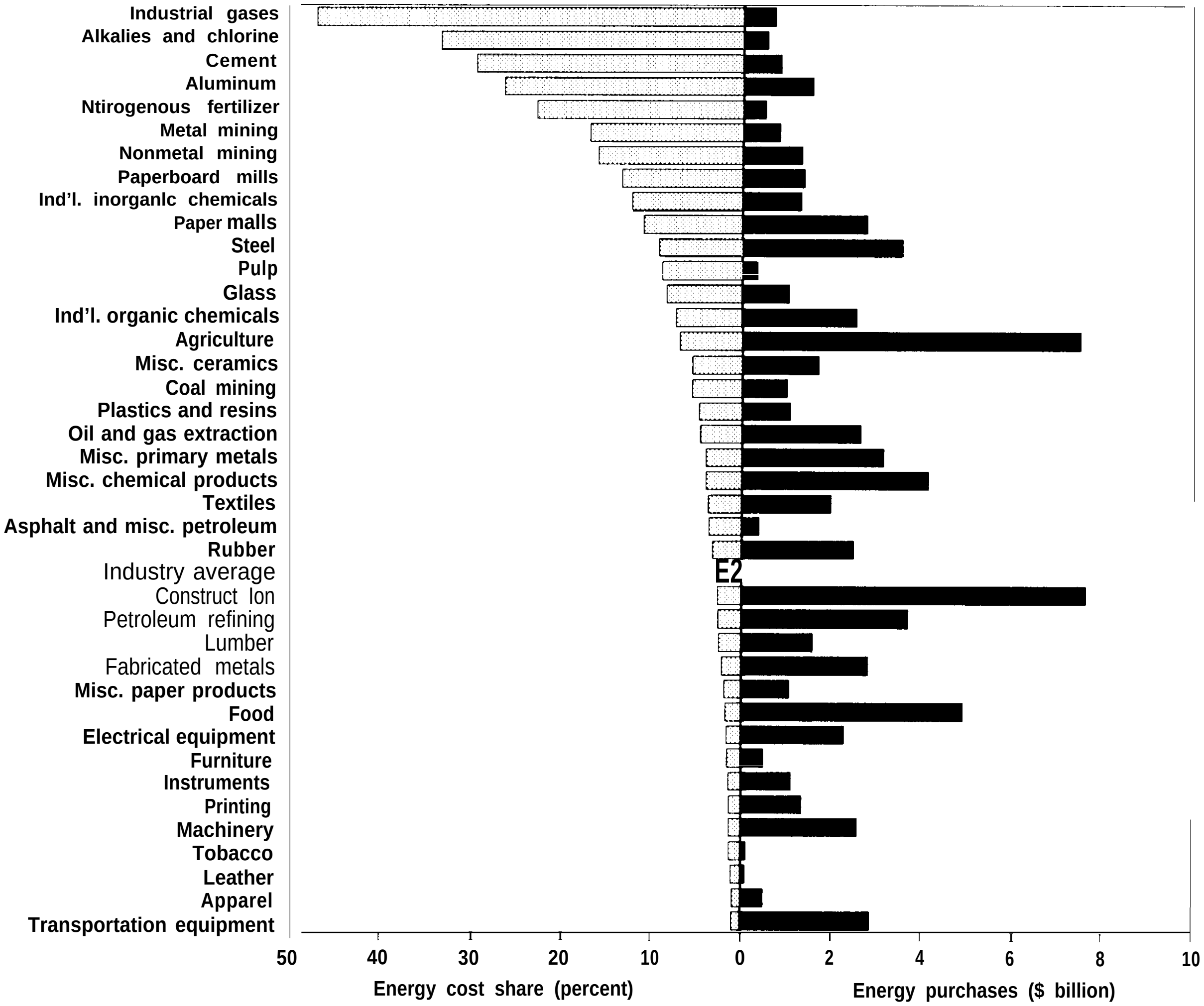
SOURCES: Manufacturlng: U.S. Department of Energy, Energy Information Administration, Manufacturing *Energy Consumption Survey (MECS), Consumption* of Energy 1988, Report No. DOE/EIA-0512(88), May 1991 and U.S. Department of Commerce, Bureau of the Census, 1988 *Annual Survey of Manufactures, Statistics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

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

INDUSTRIES AND THEIR ENERGY USE

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

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



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

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

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

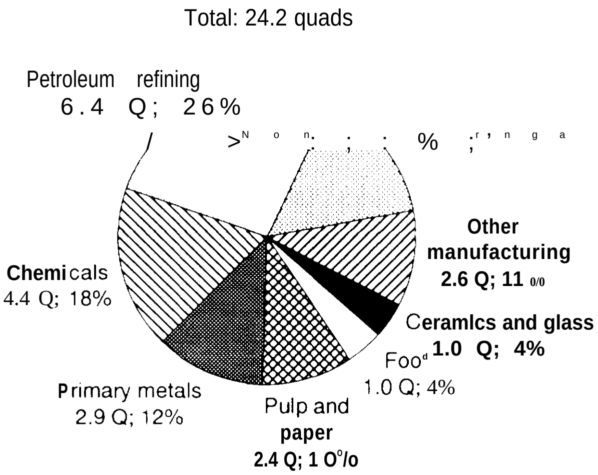
Energy costs, in terms of overall expenditures and share of production costs, are also vastly different among industries (figure 2-8). For most industries, energy represents only a small portion of production costs. Energy accounts for 5 percent or less of production costs for 86 percent of industrial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

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

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

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

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



a Nonmanufacturing includes natural gas used as lease and plant fuel, but excludes agricultural uses of natural gas.

b Other manufacturing: metals fabrication 1.4 Q, nonmetals fabrication *0.9 Q,* and miscellaneous 0.3 Q.

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

I Process Industries

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

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

---

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

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

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

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

	SIC[a]	Net electricity[b]	Natural gas	Fuel oil	Coal and coke	LPG	Other	All fuels
Process industries								
Petroleum refining	29	106	723	126	8	56	5,393[c]	6,412[d]
Chemicals	28	416	2,049	138	317	896	545[e]	4,360
Plastics and resins	2821	44	207	11	31	225	49	567
Nitrogenous fertilizers	2873	10	427	<.5	0	W[f]	W[f]	444
Miscellaneous industrial organic chemicals	2869	53	687	26	91	583	384	1,823
Miscellaneous industrial inorganic chemicals	2819	93	135	8	43	<.5	8	288
Other chemicals	—	216	593	110	152	<88	<104	1,238
Pulp and paper	26	189	431	190	315	5	1,236[g]	2,366
Paper mills	2621	98	179	103	191	2	507	1,081
Paperboard mills	2631	36	160	57	113	<.5	530	896
Other pulp and paper		55	92	30	11	3	199	389
Food	20	171	489	83	157	10	85	994
Textiles	22	101	93	26	39	3	12	275
Tobacco	21	3	2	1	17	<.5	1	25
Total process industries		987	3,787	564	852	969	7,272	4,432
Materials production								
Primary metals production	33	509	751	60	1,505	6	45	2,875
Steel	3312	138	444	47	1,418	1	18	2,067
Aluminum	3334	225	20	<.5	W[f]	<.5	9	258
Other primary metals		146	287	13	<87	5	18	550
Ceramics and glass	32	115	468	50	301	4	27	966
Cement (hydraulic)	3241	33	30	5	224	<.5	15	311
Other ceramics & glass		82	438	45	77	4	12	655
Total metal production	—	624	,219	109	1.806	10	72	3.841

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

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

[a] Standard Industrial Classification (SIC) codes.

[b] Net electricity refers to purchased electricity plus generation from noncombustible renewables minus electricity sales. It does not include electricity generated or cogenerated from combustible fuels accounted for elsewhere in the table.

[c] Includes: petroleum feedstocks and raw material inputs for the production of nonenergy products such as asphalt, waxes, lubricants, solvents, and feedstock consumption at adjoining petrochemical plants (3,290 trillion Btu); still gas (1,508); and petroleum coke (538).

[d] Excludes inputs and feedstocks that were converted to other energy products (e.g., crude oil converted to residual and distillate fuel oils).

[e] Includes: waste gas (263 trillion Btu); petrochemical feedstocks (199); and waste oils and tars (66).

[f] Withheld for data disclosure or data sampling reasons.

[g] Includes: pulping liquor (833 trillion Btu) and wood chips and bark (348).

[h] Includes: wood chips and bark (264 trillion Btu).

[i] Includes lease and plant fuel.

[j] Asphalt, road tar, and road oil used for nonenergy activities.

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

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

PETROLEUM REFINING

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

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

CHEMICALS

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

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

PULP AND PAPER

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

---

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

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

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

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

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

FOOD

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

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

I Materials Production

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

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

---

[16] Statistics from the American Paper Institute, Inc.

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

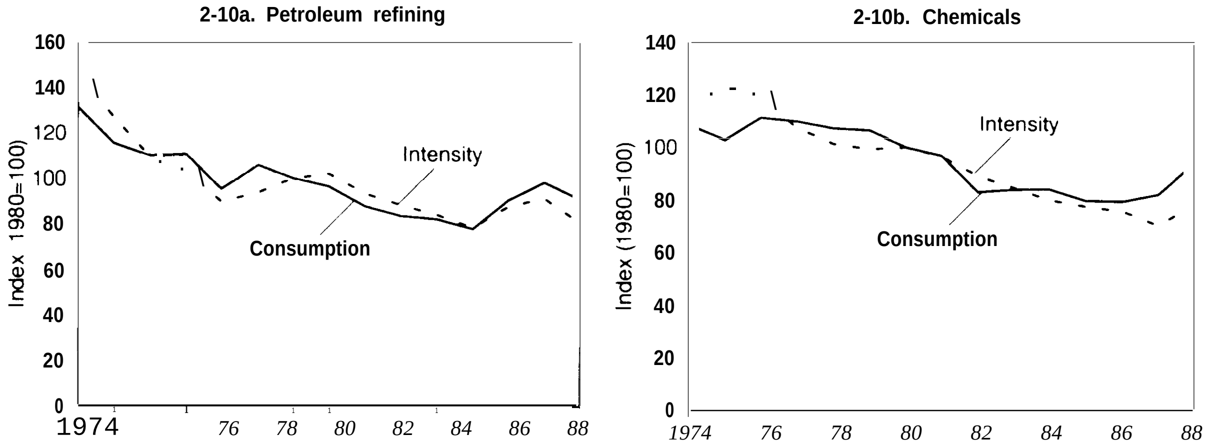
[18] U.S. Department of Commerce, Bureau of the Census, op. cit., footnote 10.

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

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

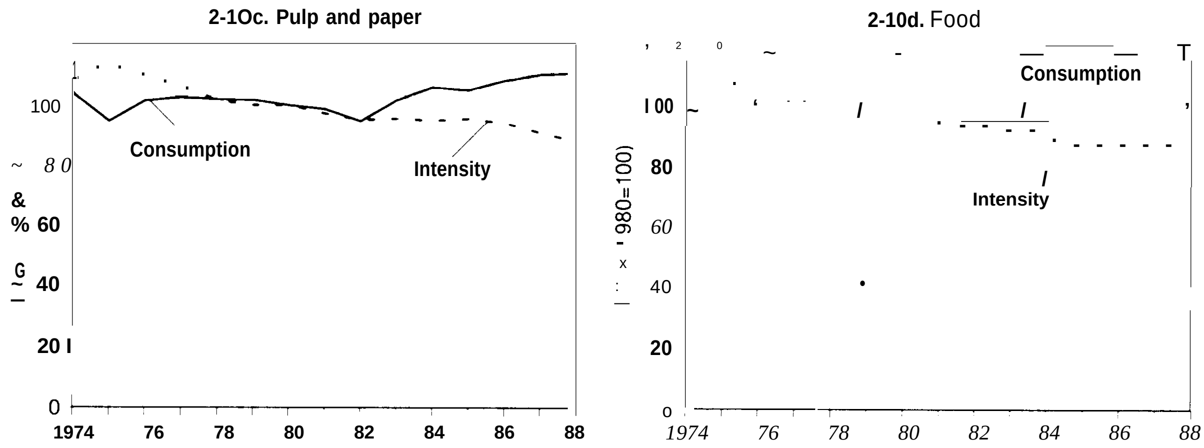
[21] OTA, op. cit., footnote 12.

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



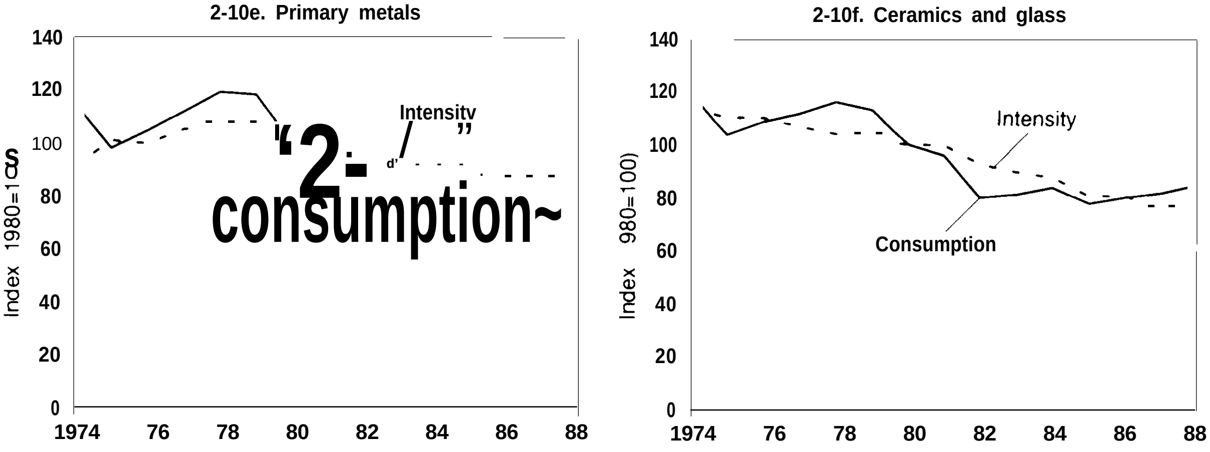
2-10a. Petroleum refining

2-10b. Chemicals



2-1Oc. Pulp and paper

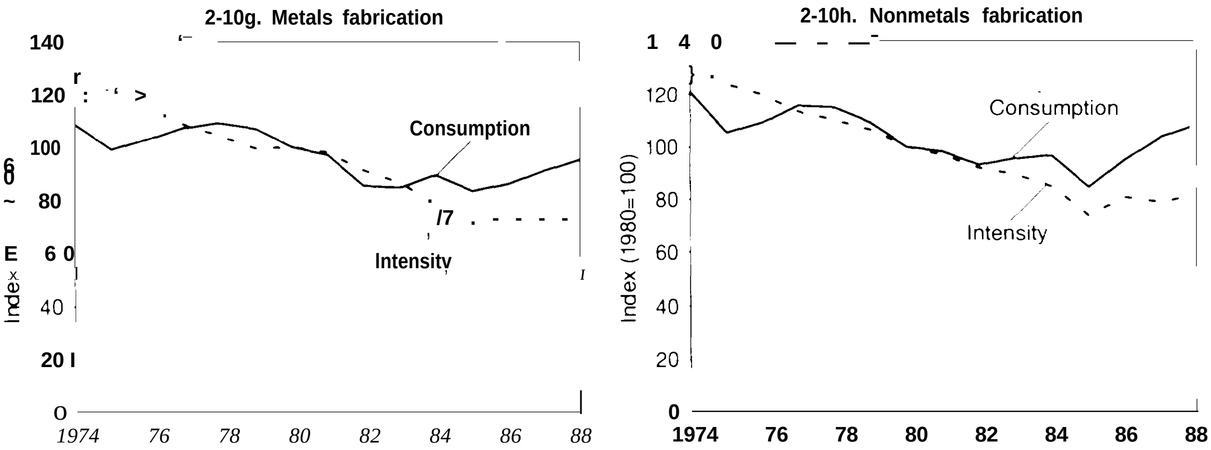
2-10d. Food

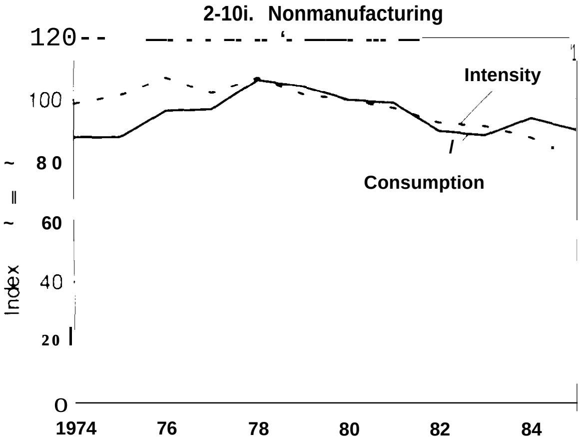


2-10e. Primary metals

2-10f. Ceramics and glass

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





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

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

PRIMARY METALS PRODUCTION

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

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

---

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

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

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

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

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

CERAMICS AND GLASS

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

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

H Metals Fabrication

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

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

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

~ Nonmetals Fabrication

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

---

[25] OTA, op. cit., footnote 12.

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

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

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

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

I Nonmanufacturing

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

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

ENERGY INTENSITY

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

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

---

[27] OTA, op. cit., footnote 12.

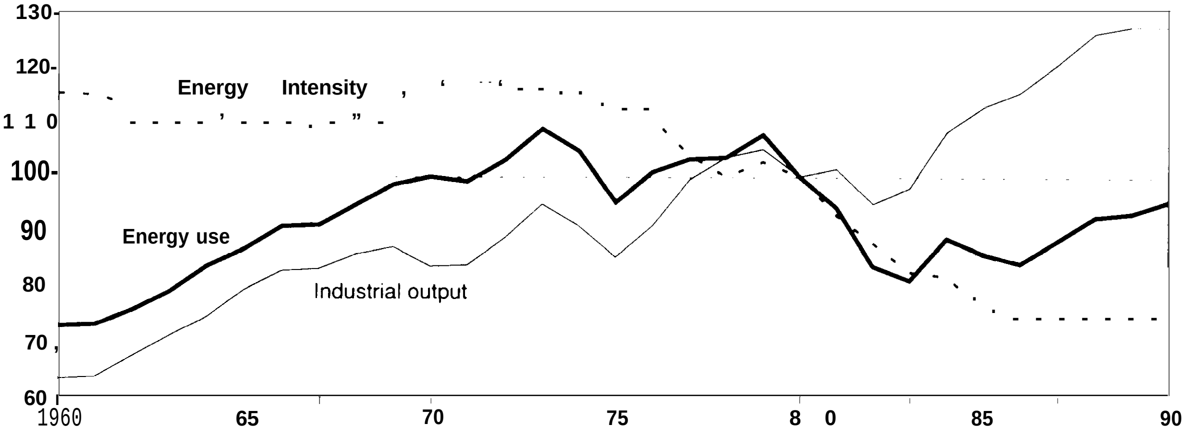
[28] U.S. Department of Energy, 1988 MECS, op.cit., footnote 15.

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

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

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

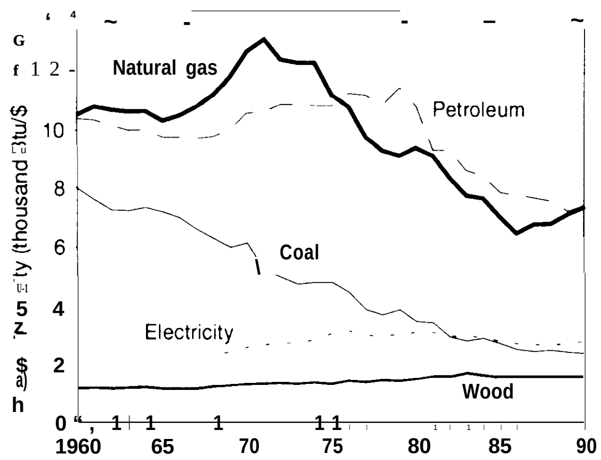
Figure 2-11—Industrial Output, Energy Consumption, and Energy Intensity, 1960-90



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

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

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



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

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

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

■ Efficiency and Structure

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

- Investment by steelmakers in modern, efficient equipment;

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

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

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

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

1 International Comparisons

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

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

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

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

---

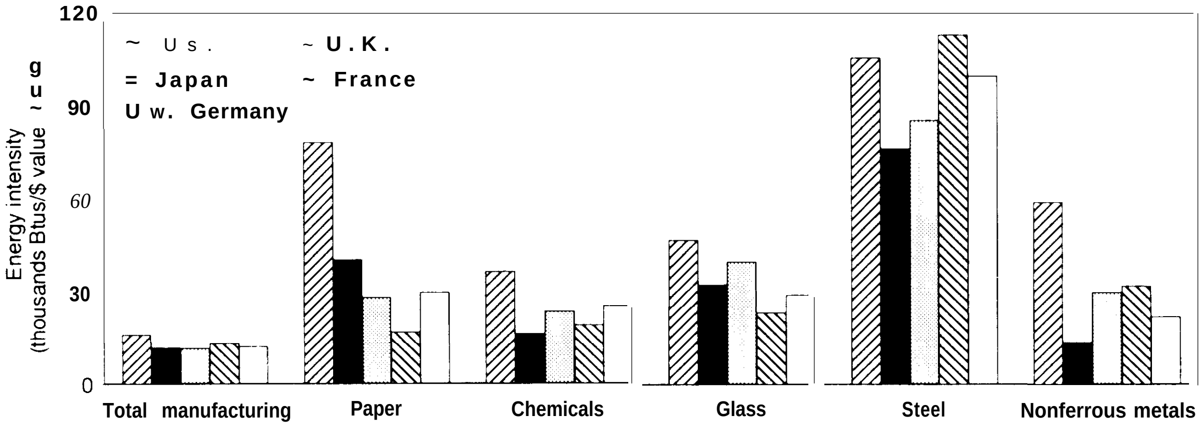
[32] C. Doblin, ''Declining Energy Intensity in the U.S. Manufacturing Sector," *The Energy Journal, vol. 9, No. 2,* pp. 109-135, 1988. U.S. manufacturing sector, 1974-1980. Annual reduction in primary energy intensity caused by structure shifts (1.1 percent) and technology improvements (1.1 percent).

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

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

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

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



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

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

OUTLOOK

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

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

---

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

- Gas Research Institute, *Industrial Natural Gas Markets: Facts, Fallacies and Forecasts,* op. cit., footnote 9;
- Gas Reseach Institute, *Annual Baseline Projection Data Book (Chicago, IL: Gas* Research Institute, annual);
- Electric Power Research Institute, *Efficient Electricity Use: Estimates of Maximum Energy Savings, EPRI CU-6746 (Palo* Alto, CA: Electric Power Research Institute, March 1990); and
- Oak Ridge National Laboratory, *Energy Efficiency: How Far Can We Go?* ORNL/TM-11441 (Springfield, VA: National Technical Information Service, January 1990).

Table 2-5-international Industrial Energy Prices, 1991

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

NOTE: Prices include taxes.

[a] Coal prices for Canada are for 1989.

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

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

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

This section discusses the results of these studies.

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

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

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

---

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

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

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

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

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

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

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

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

H National Energy Strategy, First Edition 1991/1992

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

---

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

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

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

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

I An Alternative Energy Future

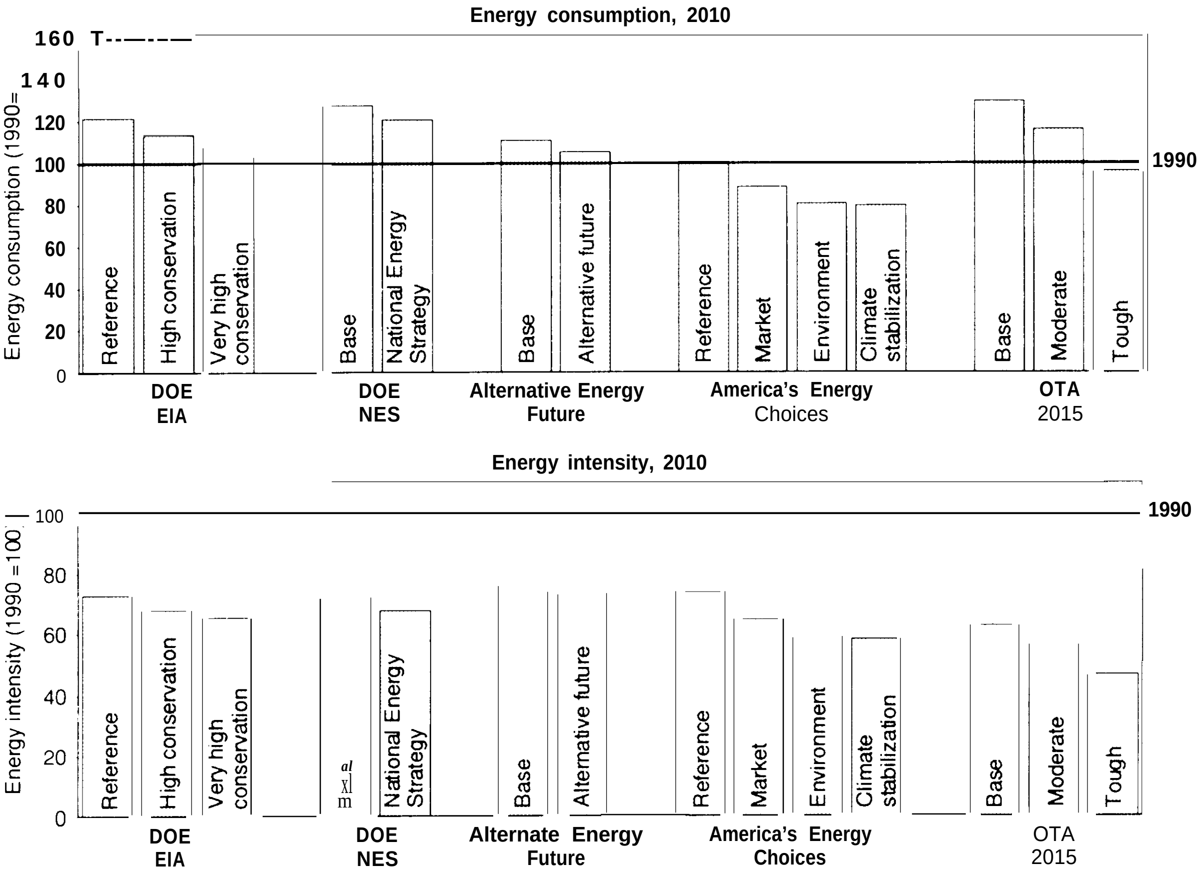
This study was written by the Alliance to Save Energy, the American Gas Association, and the Solar Energy Industries Association. It examines a free market approach to energy use with an emphasis on efficiency and clean fuels in legislation, regulation, and research and development (R&D) programs. New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

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

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

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

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



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

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

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

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

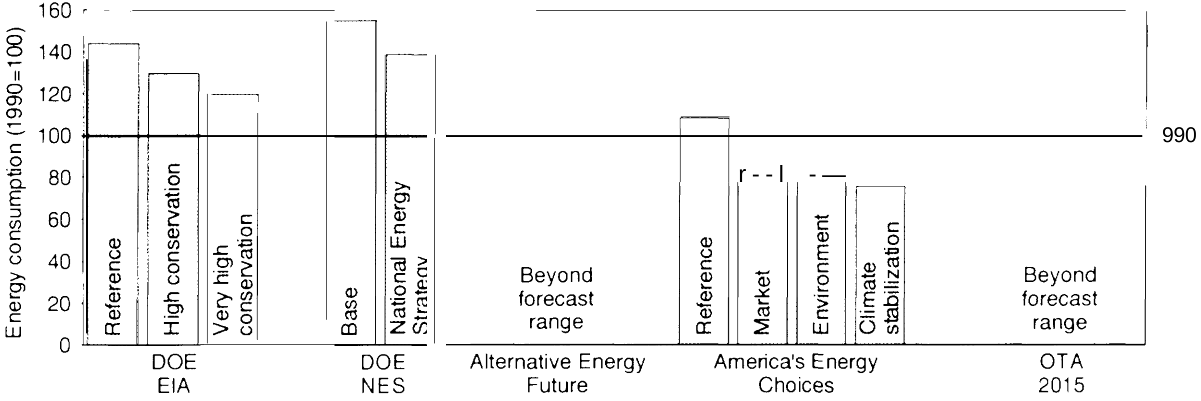
The overall GNP growth is the same as in the EIA projections.[37] However, this study incorporates: 1) a larger shift from the manufacturing sector toward the service sector and 2) greater movement from energy-intensive basic industries toward less intensive fabricating and assembly industries (table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

---

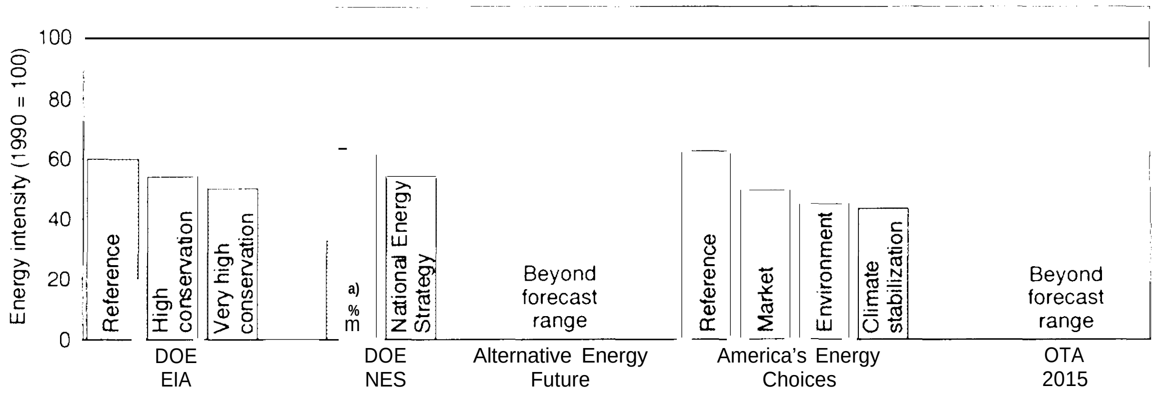
[37] The energy price assumptions are also very similar to those in the EIA study.

Figure 2-14—(Continued)

Energy consumption, 2030



Energy intensity, 2030



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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

---

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

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

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

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

I Summary

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

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

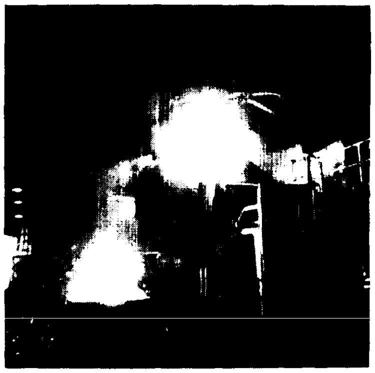
The studies generally kept industry output growth rates and industrial structure constant among their scenarios. Therefore, differing assumptions about efficiency and conservation efforts are reflected mostly in the policy cases.

Improved Technologies and Practice

3

There are many energy efficient technologies and practices—both currently available and under development—that could save energy if adopted by industry. Energy efficiency can be improved through cost-effective use of: 1) general housekeeping and maintenance programs, 2) energy management and accounting systems, 3) improved equipment and procedures for existing production methods, 4) new and better production methods, and 5) product changes (table 3-1). Most of the equipment and process enhancements are specific to particular industries, but several (e.g., heat recovery technologies, high-efficiency motors and variable-speed drives, sensors and controls, and cogeneration) have applications in many industries. These generic technologies are particularly attractive targets for government policies.

The costs and benefits of energy efficiency improvements vary widely. Minor operational changes, such as housekeeping and maintenance, are typically the cheapest, easiest to implement, and least risky, and usually, though not always, yield the smallest energy and cost savings. Production equipment changes and energy conservation add-on technologies involve larger investments, typically $100,000 to tens of millions of dollars, and may or may not be justified by reduced energy costs alone. Major process changes often require building a new facility, at costs typically exceeding $100 million, and are usually justified only by strategic, market development concerns. Energy savings are rarely sufficient to justify investments of this magnitude.



Potentially, the greatest increases in efficiency will come not from direct efforts to reduce energy consumption but from pursuing other economic goals like improved product quality, lower capital and operating costs, or specialized product markets. Many projects undertaken for nonenergy reasons yield energy efficiency gains as a secondary consequence. For example, glass

Table 3-l—Technologies and Practices Affecting Industrial Energy Intensity

Categories	Examples
Housekeeping	Piping system insulation; steam leak repairs.
Maintenance	Equipment tune up to keep it operating near design efficiency.
Energy management and accounting systems	Energy use monitoring and control equipment.
Equipment changes	
Equipment improvement	Use of high-efficiency motors; use of adjustable-speed drives.
Equipment sizing	Use of smaller, less energy-consuming equipment.
Fuel switching	Use of gas vs. coal boilers; use of steam vs. electric drives.
Process refinements	
Equipment integration	Use of heat exchangers; use of PINCH techniques at plant design and retrofit stages.
Cogeneration	Balanced steam and electricity demands.
Yield improvement and quality control	Reduced scrap and rejects.
Waste minimization	improved process control or process innovation.
Recycling	Use of scrap in the paper, steel, and aluminum industries.
Raw materials substitution	Use of higher sulfur feedstocks in the petroleum industry.
Computerized controls and sensors	improved product yield, quality, and rests.
Process change	
Same categories as for equipment changes and process refinements (above); extent of the changes and the technological and economic risks are greater.	Thin slab casting of steel. Use of direct steel making techniques.
Product shifts	
Amenity demand	Shifts away from defense activities.
Product demand	Expansion of electronics in personal and business communications.
Domestic production/trade	Use of domestic steel vs. imported steel.
Product refinement	Use of unleaded gasoline.
Materials substitution	Use of plastics and aluminum for steel in automobiles.
Product quality and performance	Use of thinner and higher quality steel.

SOURCE: Office of Technology Assessment, 1993.

producers adopted the energy-saving float process primarily for the production flexibility that it offered.1 Steelmaker have installed continuous casters more for the improved product yield than the energy savings. Metal stamping plants have implemented new techniques for cushioning presses not for the 10 percent energy savings, but for the more consistent products and lower maintenance costs.[2] Sometimes, however, pursuing improved quality or specialized markets can diminish energy efficiency. Such is the case in petroleum refining where several factors have combined to increase the energy requirements per unit of product in recent years: 1) the reduction in capacity utilization; 2) the decline in crude oil quality; 3) the increasing demand for lighter products (gasoline and liquefied petroleum gases) relative to heavier products (residual oil); and 4)

---

[1] Henry C. Kelly, Peter D. Blair, and John H. Gibbons, "Energy Use and Productivity: Current Trends and Policy Implications, " *Annual Review of Energy,* vol. 14, pp. 321-352, 1989.

[2] Marc Ross, "Improving the Energy Efficiency of Electricity Use in Manufacturing, " *Science, vol. 244,* pp. 311-317, Apr. 21, 1989.

the requirements for enhanced products such as reformulated gasoline.

At any given time, the mix of technologies used by industry ranges from outdated to state-of-the-art. Energy efficiency improves as older facilities are replaced with state-of-the-art ones.[3] In the petroleum refining, chemical, pulp and paper, steel, aluminum, cement, and glass industries, most state-of-the-art technologies use 12 to 38 percent less energy than the mix of processes currently used (table 3-2).[4] This comparison does not imply that these industries would find it economical to bring all their existing plants to state-of-the-art levels at once, but instead shows the energy savings that can be expected as plants are modernized. Energy efficiency also improves as advanced technologies are developed to become the state-of-the-art of tomorrow.[5] Advanced technologies, not yet commercialized, could possibly reduce energy use in the various processes by an additional 9 to 35 percent.

GENERIC IMPROVEMENTS

1 Housekeeping, Maintenance, and Accounting[6]

The first step in improving energy efficiency in industry is good housekeeping. Among the activities in this area are:

- carrying out inspections to encourage conservation;
- instituting training programs on operating energy-intensive equipment;
- scheduling energy-intensive activities;
- turning off equipment when not in use;
- installing and using energy monitoring equipment;

wrapping tanks and pipes with insulation; and

- repairing leaks.

Housekeeping can often save surprisingly large amounts of energy, particularly in older plants. Indeed these activities have been credited with significant portions of the efficiency gains achieved in the 1970s and 1980s.[7] Many manufacturers had housekeeping programs years ago, but have slacked off recently, because they believe ‘‘it doesn’t pay” and they cannot afford the staff to do the work.

Achieving substantial savings from housekeeping requires a well-qualified staff for carrying out energy conservation activities and top management leadership and support. Employee participation in energy conservation has proved successful at some manufacturing plants. This method can include systematic solicitation of employee suggestions for technical changes (e.g., using quality circles).[8]

Equipment maintenance is another important measure for improving efficiency. Equipment operates most efficiently when operating near

---

[3] Throughout this chapter, state-of-the-art manufacturing technologies refer to the best available technologies with demonstrated technical feasibility in actual production environments, such as in a commercial or large-scale plant. Some of these technologies that are at an early stage of commercialization may require additional development efforts to become suitable for widespread industry adoption.

[4] The ethylene process, which is nearly at state-of-the-art levels now, is excluded from this comparison range. Note that the energy figures in table 3-2 and in the industry specific portions of this chapter are calculated with purchased electricity valued at the primary rate of 10,500 Btu/kWh, because of how the figures were reported in the original sources.

[5] Throughout this chapter, advanced manufacturing technologies refer to those technologies that are under development or have been seriously considered in concept and are expected to have an impact on the industry over the next 10 to *25 years.*

[6] *Marc* Ross, ‘Energy Use in Manufacturing, ’ contractor report prepared for the U.S. Congress, Office of Technology Assessment, October 1988.

[7] U.S. Congress, Office of Technology Assessment, *Industrial Energy Use,* OTA-E-198 (Washington, DC: U.S. Government Printing Office, June 1983). Marbek Resource Consultants, *Energy Demand in Canada, 1973-1987: A Retrospective Analysis* (prepared for Energy, Mines, and Resources, Ottawa, Canada: August 1989).

[8] General employee participation in efforts to enhance product quality and productivity can also contribute to improved energy efficiency.

Table 3-2—Energy Use by Major Energy Consuming Industrial Processes[a]

Process	Current[b]	(Year)	State-of-the-art (2010)	Advanced (2010)	
Petroleum refining	*602*	(1989)	405	363	thousand Btu/barrel of crude oil
Miscellaneous chemicals					
Sulfuric acid[c]	-1,860	(1988)	-2,120	-3,230	thousand Btu/ton of sulfuric acid
Nitrogen and oxygen[d]	3,730	(1985)	3,150	2,820	thousand Btu/ton of oxygen and nitrogen
Ethylene	58.2	(1988)	57.4	52.4	million Btu/ton of ethylene
Pulp and paper[e]					
Chemical process (kraft)	39.4	(1985)	26.7	20.0	million Btu/ton of paper
Mechanical (stone groundwood)	35.1		29.0	—	
Semichemical	36.6		26.5	20.5	
Thermomechanical	40.9		31.9	28.2	
Chemimechanical (nonsulfur)	—		—	13.9	
Biological	—		—	23.2	
Repulping recycled paper	23.8		18.5	14.8	
Steel[f]					
Basic oxygen process	26.0	(1983)	16.1	—	million Btu/ton of finished steel
Electric process (scrap-based)	15.4		10.2	8.8	
Direct steelmaking	—		—	14.0	
Aluminum					
Alumina and aluminum production	196	(1980)	162	137	million Btu/ton of aluminum
Aluminum smelting only	160		135	110	
Cement[g]	*5,070*	(1988)	3,780	3,110	thousand Btu/ton of cement
Glass					
Flat glass	15,0	(1985)	10.3	6.9	million Btu/ton of glass
Container glass	15.6		12.1	8.9	
Pressed and blown glass,	27.4		22.8	15.2	
Fibrous glass	24.5		21.6	14.0	

[a] This table is a summary of detailed data presented in tables 3-4, 3-6, 3-7, 3-10, 3-12, 3-14, and 3-16.

[b] Average of currently implemented technologies.

[c] Figures for sulfuric acid are negative because the production process is exothermic—it produces more energy than it consumes.

[d] Assumes production of 58 percent nitrogen and 42 percent oxygen.

[e] Mix of paper products is 8 percent newsprint, 30 percent printing and writing paper, 4 percent industrial paper, 7 percent tissue paper, 49 percent paperboard, and 2 percent construction paper.

[f] Steel figures embody: 65 percent continuous casting and 35 percent ingot casting in the Current Case; 95 percent continuous Casting and 5 percent ingot casting in the state of the art case; and 68 percent strip casting, 27 percent continuous casting, and 5 percent ingot casting in the advanced case, Mix of steel products is 21 percent hot rolled sheet and strip, 38 percent cold rolled sheet and strip, 9 percent heavy plate, 7 percent shapes and rails, and 25 percent bars and wire rods.

[g] Cement produced from domestic clinker.

NOTE: The energy values in this table-and in tables 3-4, 3-6,3-7, 3-10,3-12,3-14, and 3-16-are unlike most others in this report in that they account for purchased electricity at 10,500 Btu/kWh. This inconsistency arises because of how the figures were reported in the original sources. That is generation and transmission losses are included.

SOURCE: Compiled from sources in tables 3-4, 3-6, 3-7,3-10, 3-12, 3-14, and 3-16.

design specifications. Poorly maintained equipment deviates from these specifications, and suffers large efficiency losses. For example, many pumps and fans are poorly maintained, and efficiencies can decrease markedly over time due to wear. One study of 84 large pumping systems, primarily in pulp and paper mills in Sweden and Finland, found that wear alone had reduced average pump efficiencies by 14 percentage points compared with their original performance.[9]

---

[9] Eric D. Larson and Lars J. Nilsson, ''Electricity Use and Efficiency in Pumping and Air Handling Systems,'' paper presented at the American Society of Heating Refrigeration and Air Conditioning Engineers Annual Meeting, Indianapolis, IN, June 1991.

General maintenance is needed to keep equipment and processes operating at specifications.

Accounting systems can also be used to help motivate energy conservation activities. In many plants, energy costs are charged to overhead accounts not to the individual departments using the energy. This gives department managers little incentive to search for energy savings. Efficiency improvements can be encouraged with accounting systems that more accurately allocate energy costs within plants.

1 Energy Management Systems[10]

Leaving on electrical equipment between production shifts and when production is below capacity is common practice in industry. While it is sometimes more energy efficient to leave equipment on rather than shut it down and start it up again, turning equipment off or down usually saves energy. Energy management systems can be used to systematically turn off or turn down process equipment, lights, and fans. Microprocessors are connected to major energy distribution lines and/or equipment to record energy use and control the equipment. Such systems have not yet been installed in most factories.

Full scale energy management systems can be expensive initially, because of the costly installation of wiring and switching devices required. In some cases, auxiliary equipment may also be needed. For example, turning off sections of a compressed air system that are not in use requires satellite compressors to serve equipment that needs air around the clock, and/or check values and controls to isolate sections of the system. The typical cost of an energy management system in an automobile plant with a load of 100 million kWh per year is about $750,000, with energy savings of about 10 percent.[11] Exact costs and savings are, of course, site specific.

~ Motor Drive[12]

Motor drive, the largest functional use of electricity in industry, accounts for about two-thirds of the sector's electricity use. Motors are used to drive a variety of applications, including:

- pumps, fans, and compressors used in fluid processing, heating, ventilation, and air conditioning (41 percent of electricity used for motor drive in manufacturing firms);
- materials processing equipment used for crushing, grinding, cutting, mixing, and forming (32 percent); and
- materials handling machinery such as cranes, conveyors, elevators, and robotics (27 percent) .[13]

Efficiency improvements on the order of 30 percent are possible in these applications through the use of: l)high efficiency motors; 2) adjustable speed-drives; 3) power conditioning; 4) better pumps, fans, compressors, and other drive equipment; and 5) better system design.

MOTORS

Standard motors, when well maintained and operated near their design points, convert electricity input into mechanical output with average technical efficiencies of 77 to 94 percent depend-

---

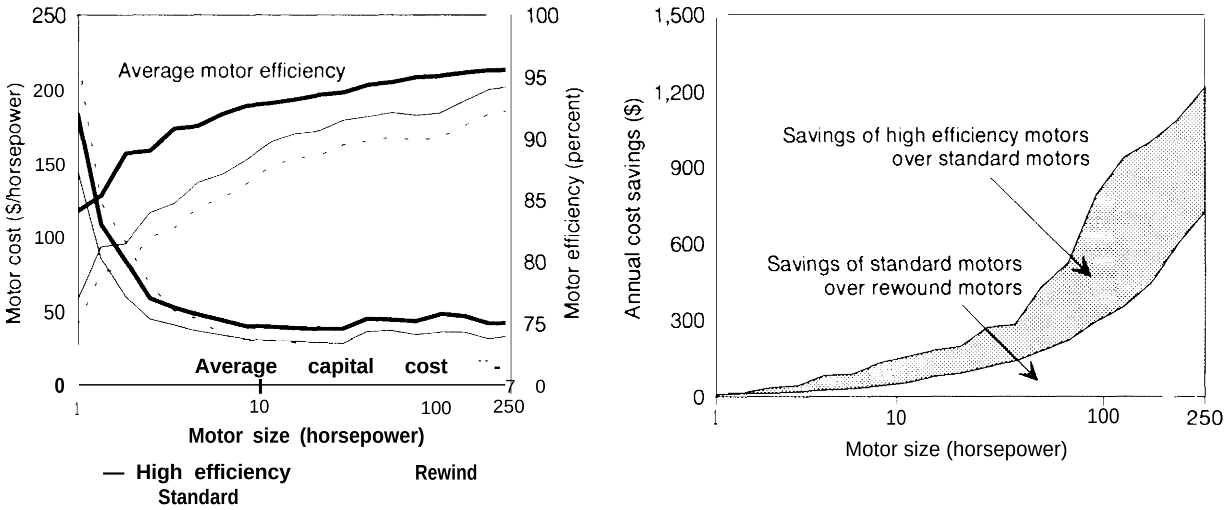
[10] Marc Ross, "Energy Use in Manufacturing," op. cit., footnote 6.

[11] Marc Ross, "Improving the Energy Efficiency of Electricity Use in Manufacturing," op. cit., footnote 2.

[12] Drawn from U.S. Congress, Office of Technology Assessment, *Fueling Development: Energy Technologies for Developing Countries, OTA-E-516* (Washington, DC: U.S. Government Printing Office, April 1992). Principal sources for the original were: Samuel F. Baldwin, ''Energy-Efficient Electric Motor Drive Systems,' Thomas B. Johansson, Birgit Bodlund, and Robert H. Williams (eds.), *Electricity: Efficient End-Use and New Generation Technologies, and Their Planning Implications* (Lund, Sweden: Lund University Press, 1989), pp. 21-58; Samuel F. Baldwin, "The Materials Revolution and Energy Efficient Electric Motor Drive Systems, " *Annual Review of Energy,* vol. 13, 1988, pp. 67-94; and Samuel F. Baldwin, "Energy-Efficient Electric Motor Drive Systems, " Princeton University, Center for Energy and Environmental Studies, Working Papers No. 91,92,93, and 94, February 1988.

[13] Electric Power Research Institute, *Electric Motors and Drives: Markets, Trends, and Applications,* Report No. TR-100423 (Palo Alto, CA: Electric Power Research Institute, June 1992).

Figure 3-l—Efficiency, Cost, and Cost Savings of High Efficiency, Standard, and Rewound Motors



This figure shows that for all sizes of motors, high efficiency models have a higher capital cost than standard models. The additional capital cost generally decreases as motor size increases. Costs are given per horsepower of motor capacity. Large motors cost more in total, but less per unit capacity. Annual cost savings are calculated based on a cost of electricity y of $.047/kWh, and a duty cycle of 5,000 hours per year with a load factor varying from 50 percent for the smallest motor sizes to 90 percent for the largest sizes.

SOURCE: OTA based on data from Steven Nadel, Michael Shepard, Steve Greenberg, Gail Katz, and Anibal T. de Almeida, *Energy-EtWent Motor Systems: A Handbook on Tehnology, Program, and Policy Opportunities* (Washington, DC: American Council for an Energy-Efficient Economy, 1991),

ing on their size (figure 3-1),[14] High efficiency motors operate at 84 to 96 percent technical efficiency.

High efficiency motors use improved design and better quality materials to decrease electrical (resistance), magnetic (core), mechanical (windage and friction), and stray losses. Electrical losses, caused by electrical resistance in wires, can be reduced by using lower-resistance materials (e.g., copper instead of aluminum) for stators and rotors. Magnetic losses can be reduced by using larger cross-sections of iron in the stators and rotors, thinner laminations, and improved magnetic materials. Mechanical losses can be decreased by using improved bearings and fan design. Stray losses can be reduced by optimal design and careful manufacturing.[15] Further improvements may result from advances such as high-performance permanent magnet motors.

Though high efficiency motors typically cost 30 percent more than standard motors, the decreased electricity usage can offset the higher capital costs in a short time. An industrial motor can use electricity worth about four times its capital cost annually.[16] Changing to high efficiency models yields larger efficiency improve-

---

[14] The efficiencies of particular brands of motors vary from these averages by several percentage points.

[15] Steven Nadel, Michael Shepard, Steve Greenberg, Gad Katz, and Anibal T. de Almeida, *Energy-Efficient Motor Systems: A Handbook on Technology, Programs, and Policy Opportunities* (Washington, DC: American Council for an Energy-Efficient Economy, 1991).

[16] Operating 5,000 h/yr at 70 percent load, a 90 percent efficient motor annually consumes 2,900 kWh/hp. At $0.047/kWh this costs $136/hp. In comparison, motors cost roughly $34/hp. Note that the unit kilowatt (kW) is used to refer to input power, while the unit horsepower (hp) is used to refer to output power. One horsepower is equal to 0.7457 kW.

ments and percentage cost savings in the small motor sizes, but greater absolute cost savings in the large sizes.

For motors larger than 5 horsepower (hp), high or premium efficiency models accounted for approximately 10 percent of sales in 1985. This market penetration is expected to increase dramatically with the institution of the motor standards set forth in the Energy Policy Act of 1992.[17]

Larger motors are often rewound, not replaced, when they malfunction. Rewinding is initially less expensive than purchasing a new motor, but ultimately costs more because of degraded efficiency. The efficiency of a rewound motor is typically about 2 percentage points below that of a new standard motor (figure 3-1). Work is needed to find methods of reducing core damage caused by the high temperatures that arise during motor rewinding.

POWER CONDITIONING

Motors and other electric devices operate most efficiently when the power they receive is the proper voltage, phase balanced, and distortion-free. However, these conditions may not always be met, because of imperfections in the power supply. Power may arrive from the grid in less than perfect condition, or it can become distorted by malfunctioning or poorly arranged equipment within industrial plants. Facilities can keep their power in good condition by repairing faulty end-use equipment or by installing specialized power-conditioning equipment to improve the power factor, reduce line voltage fluctuations, balance three-phase power, and control line harmonics.[18] These tuneups can offer small, but cost-effective gains in energy efficiency, equipment performance, process control, and reduced downtime.

DRIVE CONTROL: ADJUSTABLE-SPEED DRIVES

In many motor drive applications, control of motor speed, startup, and torque (rotational force) is needed to match the drive power with the load. “Motor speed control offers the single largest opportunity for energy-savings in drivepower systems. ’[19]

Drive speed can be easily controlled using direct current (DC) motors, but most industrial processes use fixed-speed alternating current (AC) motors because of their increased reliability and lower costs, In fluid flow applications, motors—and associated fans, pumps, and compressors—are run at constant speed and the flow is controlled with mechanical devices such as inlet vains, outlet dampers, and throttling valves. This is analogous to driving a car with the gas pedal floored, and controlling the speed with the brake. In other applications, such as mills and conveyors, various mechanical, electromechanical, and hydraulic methods are used to control the motors’ speed. Most of these control techniques are plagued with problems, including high cost, low efficiency, or poor reliability.[20] Industrial and commercial pumps, fans, and compressors, for example, have estimated average losses of 20 to 25 percent or more due to throttling or other inefficient control strategies.

Recent advances in power electronics have led to a new form of motor control, electronic adjustable-speed drives (ASDs).[21] These devices can precisely control the speed of AC motors,

---

[17] The Energy Policy Act of 1992 is discussed in chapter 1.

[18] Nadel et al., op. cit., footnote 15; and William J. McDonald and Herbert N. Hickok, ‘‘Energy Losses in Electrical Power Systems, ’ *IEEE Transactions Industrial Applications,* vol. IA-21, No. 4, pp. 803-819, 1985.

[19] Nadel et al., op. Cit., footnote 15.

[20] Ibid.

[21] The electronic ASD is the most important new motor control technology, but not the only one. Other methods of control include sequencing controls for pumps and fans, lead-lag control systems for compressors, feedback control systems that regulate rather than bypass flow, and power factor controllers that can reduce energy use of small motors in grinders, drills, and other equipment that idle with zero load much of the time. Nadel et al., op. cit., foomote 15.

thus eliminating the need for DC motors and wasteful mechanical control mechanisms. ASDs are not needed for constant-speed full load applications, so no savings are realized in these cases.

In addition to enhancing efficiency, ASDs reduce the wear on equipment and improve the operating performance of motor drive processes. They reduce equipment wear and extend equipment life by:

- avoiding the back pressures generated by conventional systems;
- permitting constant lubrication of bearings;
- allowing operation at reduced speeds; and
- permitting slow, controlled startups and shutdowns to reduce electrical and mechanical stresses on motor drive equipment.

They improve performance by:

- controlling manufacturing equipment and processes better than conventional systems can;
- isolating the motor from the power line, which can reduce problems caused by varying or unbalanced line voltage;
- providing a "ride through' capability if there is a power failure for a few cycles;
- permitting operation at higher speeds than the 60-Hz line frequency allows; and
- being easier than conventional control devices to retrofit to existing equipment.

ASDs are not without drawbacks. In particular, they can distort the shape of the normal voltage waveform in the power grid. The harmonic distortion can reduce the efficiency of motors and transformers, can also interfere with computers and communications equipment. Techniques are available to control this problem, and further work to lower the costs of control is ongoing. With proper design upfront-as opposed to onsite remediation after installation-harmonic control is relatively low cost and straightforward.

ASDs currently cost about $90 to 360per hp for motors larger than 10 hp, and can result in energy savings of 15 to 40 percent in many cases.22 The capital costs of ASDs have declined some 7 to 12 percent in real terms over the past 4 years.[23] Costs are likely to continue declining slowly as ASD technology and manufacturing processes improve, and as greater economies of scale are achieved.

The industrywide electricity savings possible by the use of ASDs are not yet well understood. Total savings will depend on a variety of factors, including the rates of cost reduction and market penetration of ASDs, and the types of part- or variable-loads driven. Further, the individual savings achieved may depend on the development of new engineering design rules that fully exploit the opportunities presented by ASDs.

ASSOCIATED EQUIPMENT

The energy efficiency of motor driven systems can often be improved by using better designed and better built pumps, fans, compressors, pipes, ducts, fittings, and materials processing and handling equipment. Pumps and fans, the most common motor driven equipment, can be made more efficient by reducing internal friction through smoother and more carefully contoured internal surfaces, tighter tolerances, and higher quality bearings. Further efficiency gains are often possible by operating pumps at higher speeds. Friction and the corresponding energy losses can be reduced in piping and systems by using smoother or larger diameter conduits and by careful choice and spacing of the fittings.

MOTOR SYSTEMS DESIGN

Motors and their power conditioning apparatus drive, control devices, and associated equipment form large and complex systems. Better design of these systems can be the source of significant energy savings.

---

[22] Nadel et al., op. cit., footnote 15.

[23] Eric D. Larson and Lars J. Nilsson, op. cit., footnote 9.

Component oversizing is a common problem among motor drive systems. Larger than needed equipment is often used to ensure that systems can meet the demands placed on them at every stage of the process. For example, motors are oversized: to handle starting electrical, mechanical, and thermal stresses, particularly with high-inertia loads; to provide a safety margin for the worst-case load over their lifetimes; and occasionally to handle plant expansion or be widely interchangeable within a plant. Motors and other components may be also oversized partly to compensate for difficulties in accurately predicting system flow rates and friction factors in advance, and to allow for the effect of the buildup of deposits on duct and pipe walls over time. The increased energy and capital costs of the larger equipment are perceived to be less than the risk of equipment failure. In manufacturing, for example, average electricity costs in the United States are equivalent to just 1.6 percent of total production costs;[24] the cost of motor failure and unplanned shutdown of the entire process line can be a much more severe penalty .[25]

The inefficiencies of equipment oversizing are compounded because of the interconnectedness of motor drive systems. When each successive element of a system is sized to handle the load presented by the previous component plus a safety margin, oversizing can quickly become excessive. The losses of the entire system can be great (figure 3-2).

The reasons for equipment oversizing are often codified into standard engineering design rules, such as manufacturing safety margins. The flexibility of ASDs may allow some relaxation of the design rules that lead to extreme oversizing, potentially reducing both energy use and capital investment.

I Steam Production and Cogeneration

Steam is used throughout industry to heat fluids and materials, and in some processes to modify the pressure characteristics of fluids and gases. Smaller quantities of steam are used to heat plant buildings. Steam is typically generated in boilers, some of which are linked to turbine and generator sets in order to cogenerate electricity. The electricity is used within the plant or sold onto the grid. In 1985, industry consumed 7.1 quads of energy to generate steam and electricity (70 billion kWh).[26] In that year, the nearly 37,000 industrial boilers had a combined capacity of 1.5 trillion Btu/h steam. The largest steam producers and electricity cogenerators are the process industries (i.e., pulp and paper, chemicals, petroleum refining, and food) and primary metals producers. They account for 79 percent of industrial boiler capacity and 94 percent of industrial cogeneration of electricity (figure 3-3).

Industry uses a variety of fuels to boil water into steam. The most heavily used are combustible process wastes and byproducts such as wood wastes and black liquor in pulpmaking, still gases in petroleum refining, coke oven and blast furnace gases in steelmaking, and various wastes in beer brewing and sugar processing. Process wastes and petroleum byproducts account for 42 percent of fuel use in steam production and cogeneration, but are the primary fuels in only 12 percent of the population of industrial boilers. They are used only in a few large industries where their value as fuel exceeds that of their reuse as process materials or feedstocks. Natural gas is the most

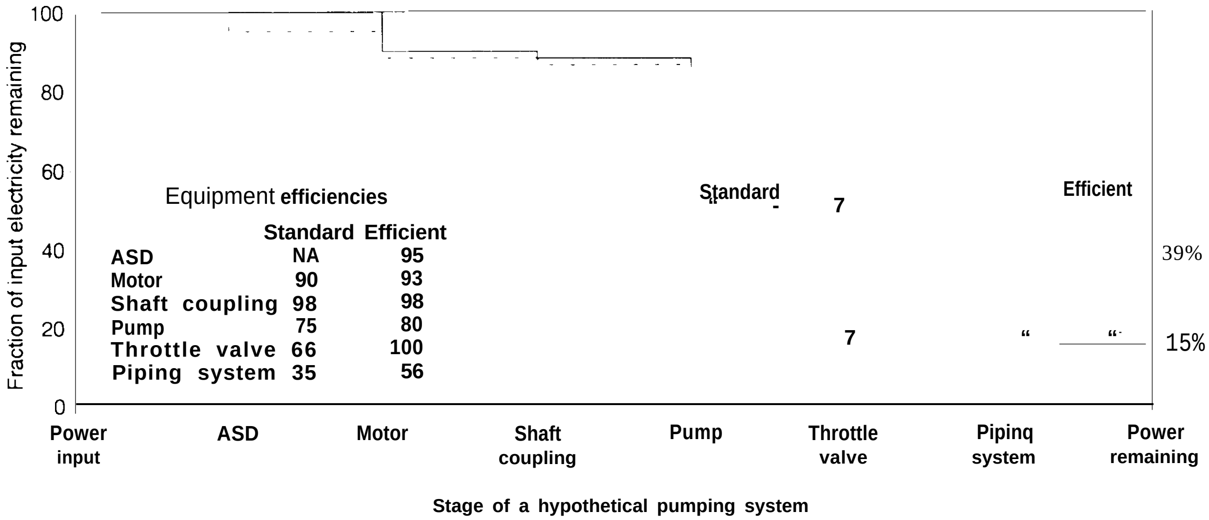
---

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

[25] A.D. Little, Inc., *Energy Efficiency and Electric Motors,* U.S. Department of Commerce, NTIS PB-259 129 (Springfield, VA: National Technical Information Service, 1976).

26 Except where noted, all figures in this section pertaining to fuel use, boiler capacity, and cogeneration capacity are based on 1985 data from Gas Research Institute, *Industrial Natural Gas Markets: Facts, Fallacies and Forecasts* (Chicago, IL: Gas Research Institute, March 1989).

Figure 3-2—Energy Losses in Hypothetical Standard and Efficient Electric Motor-Driven Pumping Systems



Equipment efficiencies

	Standard	Efficient
ASD	NA	95
Motor	90	93
Shaft coupling	98	98
Pump	75	80
Throttle valve	66	100
Piping system	35	56

KEY: ASD - adjustable speed drive.

This figure shows the useful energy remaining at each stage of the pumping systems. The efficiency profiles are those of hypothetical pumping systems, and do not represent industrywide averages. The energy losses that occur in the generation, transmission, and distribution of electricity are not included.

SOURCE: Adapted from Samuel F. Baldwin, "Energy-Efficient Electric Motor Drive Systems," Thomas B. Johansson, Birgit Bodlund, and Robert H. Williams (eds.), *Electricity:Efficient End-Use and New Generation Technologies Their Planning Implications* (Lund, Sweden: University Press, 1989), pp. 21-58.

used commercial fuel for steam production and cogeneration. It is also the fuel used in the largest number of boilers. Smaller amounts of coal and fuel oils are also used to produce steam (figure 3-4).

Many industrial facilities installed dual- and multi-fuel steam systems after the oil shocks of the 1970s. Approximately 50 percent of boilers are now capable of using more than one fuel. Dual- and multi-fuel systems are a major source of industry's fuel switching capabilities. They provide flexibility to react to market conditions and leverage to obtain favorable fuel contracts with utilities.

BOILERS AND STEAM TURBINES

Steam is produced in four basic equipment configurations: 1) steam-only boilers, 2) steam turbine cogeneration sets, 3) combustion turbine cogeneration sets, and 4) combined-cycle cogeneration sets.[27] The first two configurations incorporate boilers. Large boilers (50 million Btu/h or larger) are based on water tube technology and used to satisfy plants' basic requirements for process and power steam. Smaller boilers are predominantly fire tube units used for space heating and for backup or smaller process requirements.[28]

In a steam-only setup, the steam is piped directly from the boiler to its point of use. Steam-only boilers accounted for 60 percent of the total fuel used for industrial steam and electricity production in 1985. In a steam turbine cogeneration system, steam from the boiler is expanded in a steam turbine that turns a generator to produce electricity. Topping cycle cogenera-

---

[27] Diesel engines can also be used in cogeneration systems, generally in applications 30 kW or smaller. They currently account fOr less than 1 percent of industrial cogeneration capacity.

[28] RCG/Hagler, Bailly, Inc., *Combustion System Technology and Application Assessment: Industrial Boiler Combustion Systems* (Chicago, IL: Gas Research Institute, October 1988).

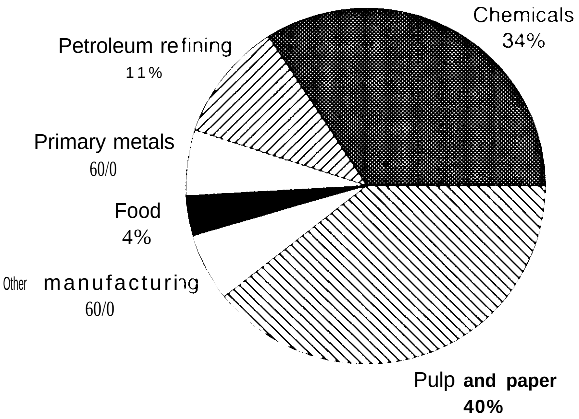


Figure 3-3—Electricity Cogeneration in Manufacturing industries, 1988

Total: 102 billion kWh

SOURCE: U.S. Department of Energy, Energy Information Administration, *Manufacturing Energy Consumption Survey (MECS), Consumption of Energy 1988,* Report No. **DOE/EIA-0512(88), May 1991.**

tion systems, the most widely used configurations, run the steam first through the generator and then to the process (figure 3-5). Bottoming cycle systems run the steam through the generator after it has been used in the process. In 1985, steam turbine systems accounted for 35 percent of fuel use for industrial steam production and cogeneration and 68 percent of the 18,700 MW of installed cogeneration capacity.

COMBUSTION TURBINES AND COMBINED CYCLE SYSTEMS

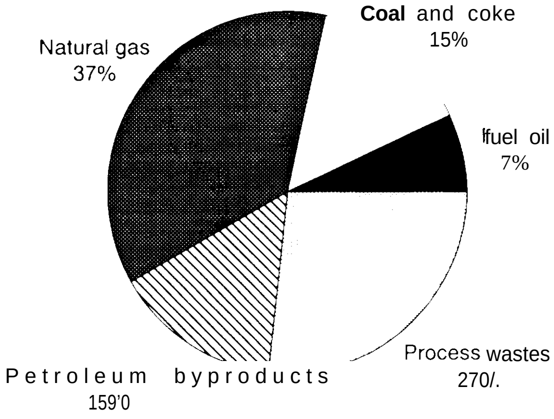
Combustion turbine and combined cycle cogeneration systems, which are fueled primarily by natural gas, rely on heat recovery units rather than boilers to produce steam. In a combustion turbine system, gas is burned in a turbine to turn an electricity generator and the exhaust gases are run through a heat recovery unit to generate steam (figure 3-5). In a combined cycle system, which is a hybrid of the combustion turbine and steam topping technologies, steam produced in combustion cogeneration is run through a steam topping turbine to produce additional electricity before it is piped to the process stream. Combustion turbine and combined cycle systems tend to be used where the ratio of electricity generated to steam produced is relatively high. In 1985, these systems accounted for 5 percent of fuel use for industrial steam production and cogeneration and 32 percent of the installed cogeneration capacity. Their share of cogeneration capacity grew from about 15 percent in 1980, because over 60 percent of the 6,700 MW of capacity added during 1980 to 1985 was combustion turbine or combined cycle.

COGENERATION

The principal technical advantage of cogeneration systems is their efficiency of fuel use. In producing both electrical and thermal energy together, cogeneration systems consume less fuel than is required to produce both forms of energy

Figure 3-4-Fuel Use in Steam Raising and Cogeneration, 1985

Total: 7.1 quads

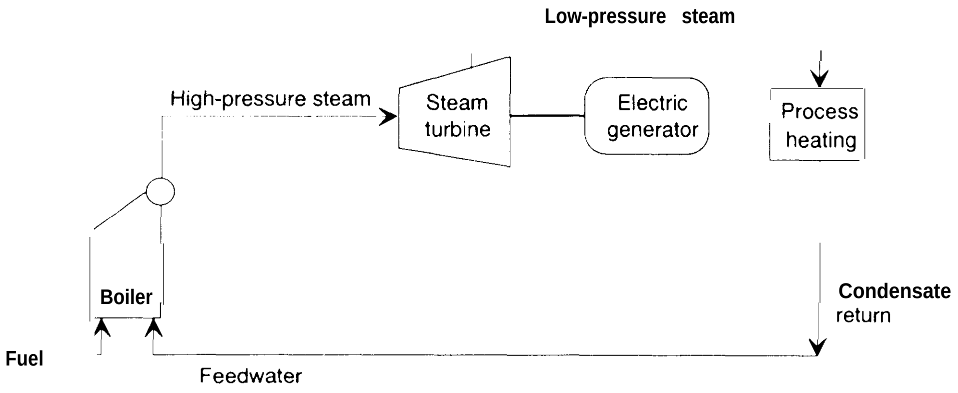


NOTE: **Petroleum byproducts are principally still gases.**

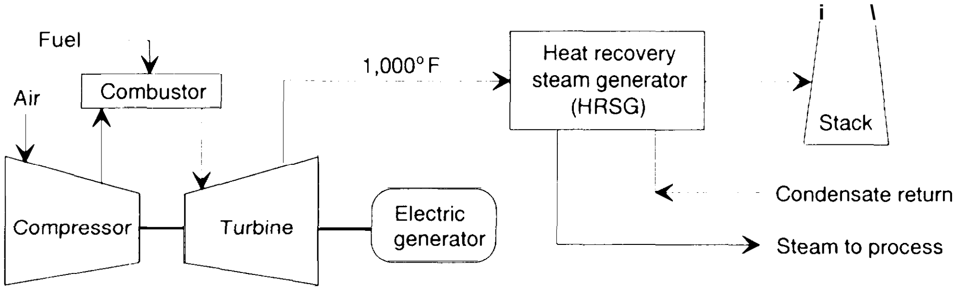
SOURCE: Gas Research Institute, *Industrial* Natural Gas *Markets: facts,* **Fallacies** *and Forecasts* **(Chicago, IL: Gas Research Institute, March 1989).**

Figure 3-5-Flowchart of Steam Turbine and Combustion Turbine Cogeneration Systems

Steam turbine, topping cycle



Combustion turbine with a heat recovery steam unit



SOURCE: Energetic, Inc., *Industry Profiles; Steam Generation* and Cogeneration, prepared for U.S. Department of Energy, Office of Industrial Technologies, Report No. DE-ACO1-87CE40762, December 1990. Original cited source is SFA Pacific, Inc.

separately, though more than is needed to produce either form alone.[29]

Cogeneration and other onsite electricity generation technologies have been used in industry since before the turn of the century. They were originally used to counter the expense, unreliability, and unavailability of electricity provided by utilities. When utility service improved, electricity purchases from utilities grew faster than onsite generation. As a result, onsite generation declined in importance.

Cogeneration capacity has grown rapidly since 1980, because of the incentives established by the Public Utility Regulatory Policies Act (PURPA) and the reversal in the long-term decline in real electricity prices. In fact, cogeneration has been the fastest growing industrial application for heat and power. Cogeneration capacity in the manu-

---

[29] U.S. Congress, Office of Technology Assessment, *Industrial and Commercial Cogeneration*, OTA-E-192 (Washington, DC: U.S. Government Printing Office, February 1983).

Table 3-3-Characteristics of State-of-the-Art Cogeneration Systems

Technology	Typical unit size (MW)	Simple cycle heat rate (Btu/kWh)	Steam to electricity ratio (lb/kWh)	Overall system efficiency (percent)
Steam topping turbine				
Backpressure only.	0.5-60	14,000-40,000	10-30	75-85
Condensing with extraction. . . .	10-100	10,000-40,000	0-30	70-80
Combustion turbine.	0.5-100	10,000-15,000	2.5-10	65-75
Diesel engine.	0.1-30	8,500-11,500	1-3	75-85

SOURCE: Energetic, Inc., *Industry Profiles: Steam Generation and Cogeneration,* prepared for the U.S. Department of Energy, Office of Industrial Technologies, Report No. DE-ACO1-87CE40762, December 1990.

facturing industries grew from 12,000 MW in 1980, to 18,700 MW in 1985, to about 25,000 MW by the end of 1989.[30] In these industries, electricity cogeneration rose from 68 to 102 billion kwh during 1980 to 1988. In 1988, cogeneration accounted for about 12 percent of manufacturers' electricity needs.[31]

PURPA made electricity sales onto the grid were more lucrative than they had been before. This increased the popularity of combustion turbine and combined cycle cogeneration technologies, because they produce greater amounts of electricity per unit of steam than steam turbine systems.

ENERGY EFFICIENCY

The energy efficiency of thermal systems can be improved by: developing and implementing better steam production and cogeneration technologies; properly maintaining steam distribution systems; increasing the use of wastes and byproducts as fuels; and increasing the effectiveness of steam and other thermal processes. Uncertainties regarding the emissions requirements of steam generation systems and the relative economics of purchased vs. self-generated electricity will play large roles in the choice of new technologies.

Use of more efficient boilers, economizers, and other heat recovery systems improves the energy efficiency of steam production and cogeneration systems.[32] State-of-the-art cogeneration systems have efficiencies ranging from 65 to 85 percent (table 3-3). Those systems that produce large amounts of steam relative to electricity generally have the higher efficiencies, while those that produce greater proportions of electricity have lower efficiencies. Advances in combustion turbine technologies (e.g., steam injection) and combined cycle systems may be able to raise the efficiencies of the more electricity-focused systems to levels comparable to those that emphasize steam.

Energy losses can also be reduced with proper attention to steam distribution systems. This includes maintenance of steam traps and in-

---

[30] Figures for 1980 and 1985 are from Gas Research Institute, op. cit., footnote 26. Figure for 1989 is from Energetics, Inc., *Industry Profiles: Steam Generation and Cogeneration*, prepared for U.S. Department of Energy, Office of Industrial Technologies, Report No. DE-AC01-87CE40762, December 1990.

[31] The 1988 electricity profile of manufacturers was: 728 billion kWh of purchased electricity; 102 billion kWh of cogenerated electricity; 10 billion kWh of electricity produced by onsite generators fueled with combustibles such as diesel and fuel oil; 3 billion kWh of electricity produced onsite from renewable sources, primarily low head hydropower; 817 billion kWh of electricity consumed; and 24 billion kWh of electricity sold. U.S. Department of Energy, Energy Information Administration, *Manufacturing Energy Consumption Survey, Consumption of Energy 1988,* DOE/EIA-0512(88), May 1991.

[32] Economizers preheat boiler feedwater using heat absorbed from the combustion products after they have passed through the steam-generating and super-heating sections of the boiler.

creased insulation of steam carrying pipes. According to insulation manufacturers, there are 29,000 miles of uninsulated steam pipes in U.S. factories.[33]

Technologies, such as fluidized-bed reactors, that can increase the potential use of low-value or previously unusable process wastes and byproducts as fuels also enhance efficiency. Fluidized beds facilitate greater use of solid and other nonstandard fuels, reducing the need for premium fuels while decreasing waste management problems.[34] Though more fluidized-bed units are being used, industry still generally views these systems as cost-prohibitive relative to conventional boiler systems.[35]

Steam is not always the most efficient method, from a thermal standpoint, of delivering heat to a process stream. There are trends toward less use of steam and greater use of direct heat or vapor recompression in manufacturing processes.

I Process Controls and Sensors[36]

Computerized process controls and sensors are used to improve the performance of individual pieces of equipment or entire processes. Examples of such devices are:

- burner controls that vary the air-to-fuel ratios in combustion systems;
- motor controls that adapt motors' speeds to their loads;
- process controls that sense characteristics such as temperature, chemical composition, and flow rate and immediately optimize them to maintain product quality, minimize waste, or vary other process parameters; and
- energy management control systems (discussed above).

Almost any process can be made more energy efficient by measuring and optimizing parameters at each point of the process. The primary advantages of process controls though, are productivity and product quality, not energy efficiency.

The importance of process controls is increasing as microelectronics technology improves. While industry has made a start in applying some automatic controls (i.e., first generation burner controls and process controls), opportunities remain for further applications. Improved sensors have the potential for r-educing energy use in individual industries by 5 to 20 percent, with overall savings for the entire industrial sector of 10 percent.[37]

I Heat Recovery and Process Integration[38]

Waste heat arises whenever fuel is burned or process materials are cooled. Capturing the waste heat and applying it to other processes has enormous potential for saving energy in industry. Recovered waste heat is commonly used in producing steam, preheating materials (such as water destined for a boiler or a product stream destined for a heater or furnace), and preheating of fuel or air destined for combustion. Industry has implemented a great deal of waste heat recovery since the oil shocks of the 1970s.

---

[33] Cited in Alliance to Save Energy, American Council for an Energy-Efficient Economy, Natural Resources Defense Council, and Union of Concerned Scientists in consultation with tbe Tellus Institute, *America's Energy Choices: Investing in a Strong Economy and a Clean Environment: Technical Appendixes,* 1992.

[34] Energetics, Inc., Industry Profiles: Steam Generation and Cogeneration, op. cit.. footnote 30.

[35] RCG/Hagler, Bailly, Inc., op. cit., footnote 28.

[36] U.S. Congress, Office of Technology Assessment, Energy Technology *Choices: Shaping Our Future,* OTA-E-493 (Washington, DC: U.S. Government Printing Office, July 1991) and *Changing by Degrees: Steps to Reduce Greenhouse Gases,* OTA-O-482 (Washington DC: U.S. Government Printing Office, February 1991).

[37] U.S. Department of Energy, Office of Industrial Programs, Research *and Development in Sensor Technology,* Report No. DOE/NBM-7012450, April 1987.

[38] U.S. Congress, Office of Technology Assessment, Energy *Technology* Choices: *Shaping Our Future,* op. cit., footnote 36.

The two principal traditional approaches to heat recovery are: 1) transferring heat from high-temperature waste heat sources to more useful media such as steam, and 2) raising the temperature of low-temperature streams so they can be useful as heat sources. Heat exchangers are used for the former approach and vapor recompression and heat pumps are used for the latter.

Process integration is another method of preventing waste heat losses. This technique involves designing processes so that the number of heating and cooling steps are minimized and that heat sources are in close proximity to processes where the heat can be used. ''PINCH' analysis is a systematic design methodology that can be used to further process integration, in either existing or greenfield plants. It helps identify the optimum process configuration for low energy use as well as low capital and operating costs. PINCH also helps reduce pollutant emissions and increase production capacity.

I Catalysts[39]

Catalysts are used in many industries to facilitate chemical reactions. The petroleum refining and chemicals industries rely heavily on catalysts to perform a variety of functions, including raising gasoline octane levels, removing impurities, and converting low-grade hydrocarbons to higher value products. Improved catalysts can increase chemical reaction rates and lower operating temperatures and pressures, thereby reducing heating and compression requirements and improving energy efficiency.

The discovery and use of new synthetic zeolites as catalysts have contributed to energy efficiency gains in both the petroleum refining and chemicals industries. Considerable effort has been spent to identify and develop unique zeolites for use in synfuels production, petrochemical manufacture, and nitrogen oxide (NO=) abatement.[40] In the pulp and paper industry, catalytic reactions can be used to recover organic acids from waste streams. Typically, the wastes are dumped because there is no method for extracting the acids unless the streams are first concentrated. A catalytic process can convert the organic acids to hydrocarbons, which can be easily separated from water.[41]

I Separation[42]

Physically separating two or more components in a mixture is one of the most energy-intensive processes in the industrial sector. Separations account for about 20 percent of industrial energy use.

Distillation, the most common method of separating liquids, is particularly energy-intensive. However, distillation retrofit projects offer significant potential for energy savings. For example, a small increase in the number of trays in a distillation column can reduce energy use. Also, improvements in distillation control technologies result in lower energy consumption as well enhanced product quality. It is estimated that improvements in the distillation process can reduce energy consumption by 10 percent.[43]

Alternative approaches to conventional distillation include vacuum distillation, freeze crystallization, solvent (liquid-liquid) extraction, membrane techniques, pressure swing adsorption, and mercury or asbestos diaphragm electrolytic processes. The increased cost-effectiveness of turbocompressors and advances in vacuum pumps and cryogenic technology have vastly increased the relative attractiveness of both vacuum distillation and freeze crystallization. Crystallization is

---

[39] Ibid.

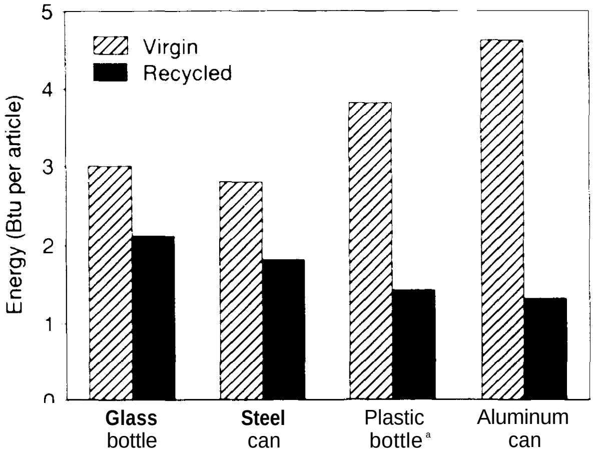
[40] Oak Ridge National Laboratory, *Energy* Technology R&D: *What Could Make a Difference*? vol. 2, Part 1, ''End-Use Technology, " ORNL-654411 V2/P1, December 1989.

[41] Ibid.

[42] U.S. Congress, Office of Technology Assessment, *Energy* Technology *Choices: Shaping Our Future,* op. cit., footnote 36.

[43] Oak Ridge National Laboratory, *Energy Technology R&D: What Could Make a Difference?* op. cit., footnote 40.

Figure 3-6-Energy Use in the Production of Virgin and Recycled Containers



a Theoretical value, **plastic bottles are not now made of recycled material.**

SOURCE: Marc H. Ross and Daniel Steinmeyer, "Energy for Industry," ***Scientific American, vol. 263, No. 3,*** **September 1990, pp. 89-98.**

often a more energy efficient separation technique than evaporative (distillation) processes, because freezing requires less energy (about 150 Btu/lb of water) than boiling (about 1,000 Btu/lb of water).

One of the most promising alternative separation methods is solvent extraction. This technology uses specialized solvents to selectively dissolve components of liquid-liquid mixtures. Its use in the chemicals industry is growing. In 1984, the Office of Technology Assessment (OTA) noted that the use of solvent extraction in a synthetic fiber plant saved an estimated 40,000 barrels of oil equivalent annually.44

Membrane separations are based upon the principle that components in gaseous or liquid mixtures permeate membranes at different rates because of their molecular characteristics. One of the major advantages of membrane separation systems is that they can improve product quality. Gas separation is perhaps the largest growth market for membrane technology, but there are many other potential applications in the chemicals and food and beverage processing industries.

I Materials Use: Yield Improvements (Waste Reduction) and Recycling (Waste Use)

Improved use of process materials holds large potential for energy savings. Rejected (off-specification) products require nearly as much energy and materials to produce as do salable products. Process yield improvements result in less waste generation and save the energy embodied in the rejected products. They also result in large cost savings and extend production capacity. Continuous casting in the steel industry is an example of a yield-improving technology that saves large amounts of energy. Computer control and sensors (see discussion above) are an integral part of most yield-improving technologies.

Recycling scrap, whether from downstream fabricators or postconsumer wastes, results in energy savings in most industries. In aluminum production, 5 percent as much energy is required to melt scrap as to smelt the same amount of molten metal from ore. Smaller, yet significant, energy savings are possible for other materials (figure 3-6).

Reuse of process wastes and byproducts for their materials or energy value saves energy and reduces disposal treatment costs. Use of traditionally discarded wastes, such as organic byproduct gases, organics in waste streams, water, and steam

---

[44] U.S. Congress, Office of Technology Assessment, *U.S. Vulnerability to an Oil Import Curtailment: The Oil Replacement Capability, OTA-E-243 (Washington DC:* U.S Government Printing Office, September 1984).

condensate, offers many energy-saving opportunities.

PROCESS INDUSTRIES

1 Petroleum Refining[45]

Petroleum refineries process the various hydrocarbon compounds in crude oil into fuels and other useful products. The hydrocarbons are first separated from one another, then converted and reorganized into more valuable forms, and finally blended into products. Along the way, contaminants such as sulfur and heavy metals are removed and beneficial compounds such as detergents are added. Four major types of processes are used in petroleum refining: separation, conversion, reorganization, and finishing.

Typical refinery products, from lightest to heaviest, include: liquefied petroleum gases (LPG); gasoline and aviation jet fuel; petroleum solvents; kerosene; heating oil and diesel fuel (the middle distillates); residual fuel oil; petroleum coke; and asphalts (bitumens).46 Depending on their geographical location, customer demand, and seasonal needs, refiners can substantially alter their product slate. In winter, for example, less gasoline and more heating oil are produced.

Petrochemicals, such as ethanol, styrene, ethyl chloride, butadiene, and methanol, are also often produced at refineries. These intermediates are used as feedstocks in the manufacture of plastics, synthetic rubbers, synthetic fibers, and other products. There are many advantages to producing these chemical building blocks at refineries, and the oil industry has undertaken their manufacture on a large scale.

Most of the energy consumed in petroleum refining comes from the petroleum itself. A rule of thumb is that it takes one barrel of oil to refine ten. Refinery gas accounts for nearly half of the energy used, Petroleum coke, residual fuel oil, and LPG are also commonly used. Natural gas, accounting for 20 percent of energy use, is the most heavily used purchased fuel.

On average, about 600,000 Btu are used to process a barrel of oil into its various products (based on 1989 data) .47 The most energy-intensive steps are the reorganization and distillation (separation) processes. Widespread adoption of state-of-the-art technologies can reduce energy consumption by about one-third (tables 3-4 and 3-5).[48] The biggest improvements are in the early stages of refining, the separation, coking, and visbreaking steps. Advanced technologies, not yet commercialized, could possibly reduce energy use an additional 10 percent.[49] Most of these potential gains come from general conservation measures such as alternate-fuel fluidized-bed boilers, improved combustion processes, and low-grade waste heat recovery, and from improvements in the akylation process.

The greatest single loss of energy in a refinery occurs during the final cooling of process streams. Where feasible, the low-level heat is transferred to other process streams, thus reducing the energy needed for cooling. The opportunities for recovering significant amounts of low-level heat are much greater in new facilities, designed to optimize heat recovery, than in existing plants. In

---

[45] "Petroleum processing," "Cracking," "Hydrocracking," and "Reforming processes," *McGraw-Hill Encyclopedia on Science and Technology* (New York, NY: McGraw-Hill, 1987). "Petroleum," *The Academic American Encyclopedia, Online Edition* (Danbury, CT: Grolier Electronic Publishing, 1991). Energetic, Inc., Industry *Profiles: Petroleum,* prepared for U.S. Department of Energy, Office of Industrial Technologies, Report No. DE-AC01-87CE40762, December 1990.

[46] Liquefied petroleum gases (LPG) are ethane, propane, butane, and various other natural gas and petroleum Products.

[47] Energetic, Inc., *Industry Profiles: Petroleum,* op. cit., footnote 45.

[48] Supra, foomote 3.

[49] Supra, foomote 5.

Table 3-4-Energy Use by Petroleum Refining Technologies

	Process mix (bbls of process stream per bbl of crude oil)			Energy use (thousand Btu per bbl of process stream)		
Process	Current (1989)	State-of-the-art (2010)	Advanced (2010)	Current[a] (1989)	State-of-the-art (2010)	Advanced (2010)
Separation						
Atmospheric distillation	**1.00**	1.00	1.00	99	38	84b
Vacuum distillation	**0.44**	0.44	0.44	96	58	**35**
Conversion						
Delayed coking/visbreaking[c]	**0.12**	**0.13**	**0.13**	**134**	58	**71b**
Catalytic cracking	**0.35**	**0.35**	**0.35**	**129**	123	**90**
Catalytic hydrocracking	**0.07**	**0.08**	**0.08**	**223**	202	**201**
Reorganization						
Catalytic reforming	**0.24**	0.24	0.24	349	349	**349**
Alkylation	0.06	0.06	0.06	627	561	**313**
Isomerization	**0,03**	0.03	0,03	154	154	**154**
Hydrogen production[d]	**0.16**	0.16	0.16	323	323	**323**
Finishing						
Catalytic hydrotreating	**0.57**	0,58	**0.58**	**180**	177	**180b**
Not ***accounted fore***	1.00		—	**104**	—	—
Genera/ corrservatione	1.00	1.00	**1.00**	·		-54
Total	1.00	**1.00**	**1.00**	**602**	405	363

a Average of current implemented technologies.
b Most improvements from advanced technologies are included in the General conservation category.
c Energy use values are averages for coking operations.
d Units for production are billion cubic feet, and for energy use are thousand Btu per thousand cubic feet of hydrogen.
e Bbls are barrels of crude oil.

NOTE: Purchased electricity is counted at 10,500 Btu per kWh; generation and transmission losses are included. Estimated losses in 1989 were approximately 44.0 thousand Btu per barrel of crude oil.

SOURCE: Energetics Inc., *Industry* ***Profiles: Petroleum,*** prepared for the U.S. Department of Energy, Office of Industrial Technologies, Report No. DE-AC01-87CE40762, December 1990,

general, improved heat exchange can reduce refinery energy use by about 9 percent.[50]

Process heaters and steam boilers also offer opportunities for reducing energy use. The options include: using stack gas analyzers and combustion control instrumentation to improve combustion; using air preheater **to** reduce stack gas temperatures and heat incoming combustion air; and installing convection sections at the heater outlets to heat incoming feed or to generate steam.

Continued improvements in computer control systems and sensors offer energy-savings benefits, as well. In addition to reducing energy use, these systems improve process performance, increase output, and optimize product specifications. A number of energy management control systems are available today. One control system company estimates that energy savings of 5 to 10 percent can be realized in the petroleum refining industry.[51]

SEPARATION: DISTILLATION

Distillation is the primary process for breaking down crude oil into its constituent hydrocarbons.

---

[50] R.O. Pelham and R.D. Moriarity, "Survey Plants for Energy Savings, " *Hydrocarbon Process,* vol. 64, No. 7, pp. 5 1-56; reported in Oak Ridge National Laboratory, *Energy Technology R&D: What Could Make a Difference*? op. cit., footnote 40.

[51] Oak Ridge National Laboratory, Energy *Technology R&D: What Could Make a Difference?* op. cit., footnote 40.

Table 3-5-Major Energy Saving Features of Improved Petroleum Refining

Process	State-of-t he-art	Advanced
Separation		
Atmospheric distillation	Reflux-overhead vapor recompression (20) Staged crude preheat (13) Air preheater (12) Intermediate reboilers and condensers (7) Split tower operation (5) Improved fractionation (4) Improved instrumentation and control (1) Two-stage condensation (<O.5)	Advanced vapor recompression (15) Advanced control strategies for thermal efficiency (5)
Vacuum distillation	Mechanical vacuum pumps (35) Improved fractionation (3)	Dry vacuum column operation (33) fluid atmospheric resid process (ART) (28)
Conversion		
Delayed coking/visbreaking	Fluid coking to gasification (FLEXICOKING) (57) Mechanical vacuum pumps (19)	fluid-bed vacuum resid process (ART) (102) Soaker visbreaking (60) HDH hydrocracking (reduced hydrogen and severity) (27)
Catalytic cracking	Turbine power recovery train (6)	FCC/improved catalysts and process (39)
Catalytic hydrocracking	Hydraulic turbine power recovery (21)	New catalysts (low temperature and pressure) (22)
Reorganization		
Alkylation	Improved catalysts (66)	Polymerization processes (31 4)
Finishing		
Catalytic hydrotreating	Hydraulic turbine power recovery (3) Operating modification (lower pressure, less recycle) (1)	
General conservation		Alternate-fuel fluidized-bed boilers (25) Improved combustion processes (17) Low-grade waste heat recovery (13)

NOTE: Figures in parentheses are estimates of energy savings, in thousand Btu/barrel of the particular process steam. In general conservation, the energy savings are in thousands of Btu/barrel of crude oil.

SOURCE: Energetic, Inc., *Industry Profiles.' Petroleum,* prepared for the U.S. Department of Energy, Office of Industrial Technologies, Report No. DE-AC01-87CE40762, December 1990.

It operates on the principle that the various hydrocarbons boil at different temperatures. When the heated crude oil is fed into a distillation column (tower), the lighter hydrocarbons (fractions) vaporize and rise. As they ascend the fractions decrease in temperature and condense into liquids. They then flow downward into hotter sections of the column and are revaporized. This process continues until the various fractions have achieved the appropriate degrees of purity. They are then tapped at various positions along the tower. The lighter fractions are tapped off from the top of the tower; heavier fractions are tapped from lower on the tower.

The initial processing of crude oil is done in atmospheric distillation columns. Temperatures within the columns gradually rise to about 640 ‘F. Large amounts of steam (about 1 to 2 lb/gal of oil) are added to reduce the boiling temperatures by partial pressure effects. Light end fractions, such as propane and butane, come off the top and are sent to the gas fractionation plant. Napthas, kerosene, heating oil, diesel fuel, and heavy gas oil are tapped successively lower on the column and are sent to various conversion and finishing processes. The heavier, high-boiling-point, bottom-of-the-barrel products are sent to a vacuum distillation unit for further separation.

Light end products are separated from one another in a series of gas fractionation columns. In a fractionation column, the gases are brought into countercurrent contact with condensate. With proper adjustment of the condensate and gas flow rates, the more volatile hydrocarbons are concentrated into the gas and the less volatile ones are concentrated into the condensate. Placed in a series, fractionating columns can be used to separate the light ends into fuel gases, propylene, propane, butylenes, iso-butane, and n-butanes.

Heavy constituents are not removed in the atmospheric distillation step, because of their high boiling points and their temperature sensitivity. They are distilled in vacuum distillation columns. The partial vacuum lowers their boiling points to a range where distillation can occur without excessive thermal decomposition.

Separation accounts for 23 percent of the energy used in refining. State-of-the-art technologies such as vapor recompression, staged crude preheating, air preheater, and intermediate reboilers and condensers can reduce energy use at this stage by about 55 percent.

CONVERSION: CRACKING

Cracking is used to convert heavier, lower value hydrocarbons into lighter, higher value ones. This is accomplished by breaking apart the chains of hydrocarbon molecules to decrease their size and by adding hydrogen to raise their hydrogen-to-carbon ratio. Cracking is carried out by catalytic, hydrocracking, and thermal methods.

Catalytic cracking is used to convert intermediate- and high-boiling point distillates into gasoline. It is used to shift refinery output to meet changes in market demand, because of its flexibility in converting a wide variety of fractions. Feed oil and a powdered catalyst are pumped together into a fluidized-bed reactor, which is coupled to a catalyst regenerator. The hydrocarbon molecules are broken by carbonium ions formed on the catalyst (typically silica-alumina zeolite) during various reactions occurring at 850 to l,025°F. During cracking, coke is deposited on the catalyst. When the catalyst is regenerated, the coke is burned to provide the heat for the cracking reaction.

Hydrocracking is used to convert highly aromatic fractions, which severely degrade the catalysts used in catalytic processes, into high-octane gasoline and aviation jet fuel. The feed oils are pumped along with hydrogen through a two-stage, freed-bed catalytic unit operating at high pressure (1,000 to 2,500 psig) and moderate temperature (500 to 750 F). Two main reactions occur in a hydrocracking unit, the addition of hydrogen to the molecules and the subsequent conversion of the fractions into the product fuels.

Thermal cracking methods are used to convert low-grade residual oils. These fractions cannot be converted by catalytic methods, because they subject catalysts to excessive coke buildup and contamination by inorganic components. The fluid coking, delayed coking, and visbreaking processes used on the low-grade residuum coming from the vacuum distillation step are based on the thermal cracking mechanism. Petroleum fractions are pumped through steel tubes coiled within a furnace. The 850 to 1,1OOOF temperatures cause thermal decomposition of the hydrocarbons to take place. The heat breaks the carbon-to-carbon bonds in the molecules by a flee-radical mechanism.

Conversion accounts for 13 percent of the energy used in refining. Use of state-of-the-art technologies such as fluid coking to gastification, mechanical vacuum pumps, and hydraulic turbine power recovery can reduce conversion energy by about 16 percent.

REORGANIZATION: REFORMING

Reforming, an extension of the cracking process, is used to raise the octane number of gasoline. Octane ratings are enhanced by reorganizing hydrocarbon molecules, principally by changing their structure but also by increasing their volatility (decreasing their size).[52] Reforming can be accomplished by thermal methods, but catalytic techniques have made them obsolete. Catalytic reforming is usually conducted by heating the feed (naptha) to 840 to 965°F in a furnace and then passing it over hydrogen-dehydrogenation catalysts, in the presence of hydrogen, in a fixed-bed reactor.[53] Moving-bed and fluidized-bed reactors can also be used. The resulting product (reformate) is stabilized (light end fractions are removed) and used directly as gasoline or as a blending stock for aviation jet fuel.

The main reaction is dehydrogenation, so hydrogen is produced in large quantities, The hydrogen is recycled through the reactor to provide the atmosphere necessary for the chemical reactions and to protect the catalyst from carbon buildup. Excess hydrogen is vented and used as a reactant in hydrocracking, hydrotreating, and chemical (e.g., ammonia) manufacturing, or as a fuel.

Reorganization accounts for 29 percent of the energy used in refining. These processes have relatively low production levels, but are the most intense energy users in the refinery, averaging about 380,000 Btu per barrel of product.[54] Little improvement in energy efficiency can be expected from using state-of-the-art technologies. The development and use of advanced polymerization processes, though, could possibly cut energy use in the alkylation process by half,

FINISHING: TREATING

Treating processes are used to remove detrimental components from petroleum fractions. Hydrotreating is the most widely used finishing process. It is a catalytic process that can be used to remove impurities (e.g., sulfur, nitrogen and oxygen), to stabilize products, correct color and odor problems, and improve other product deficiencies. Other finishing processes, such as solvent extraction, solvent dewaxing, acid treatment, and clay treatment are used to a lesser extent to perform selected finishing functions.

Finishing accounts for 17 percent of the energy used in refining. Use of state-of-the-art or advanced technologies are expected to yield little improvement in the efficiency of these processes.

ENERGY EFFICIENCY[55]

Environmental concerns about automobile emissions (carbon monoxide and nitrogen oxide) will increasingly govern the characteristics of refined products and refinery operations. Motor fuels must meet both high octane and high environmental quality standards. To meet these standards, refiners are making greater use of hydrocracking and reforming processes. Use of alkylation and isomerization processes is also increasing. The increased operating severity (increases in processing temperature, pressures, and feedstock rates) in these energy-intensive processes will continue to exert upward pressure on energy consumption in refineries. Advanced tech-

---

[52] Changes in the molecular structure include the conversion of n-paraffins to isoparaffins, olefins, and aromatics, and of naphthenes to aromatics. The most important chemical reorganization reactions that occur reforming are dehydrogenation, hydrogenation, aromatization cyclization, isomerization, polymerization and alkylation.

[53] The composition of a reforming catalyst is dictated by the feed and the desired product, Typical catalysts are molybdena-alumina, chromia-alumina, and platinum on an *alumina or silica-alumina* base.

[54] In the case of hydrogen production, 323,(X30 Btus per thousand cubic feet of hydrogen.

[55] Energetic, Inc., *Industry Profiles: Petroleum*, op. cit., footnote 45.

nologies to increase octane and concurrently reduce processing energy are needed.[56]

1 Chemicals

The chemical industry encompasses over 12,000 plants producing more than 50,000 chemicals and formulations.[57] Among the products are organic and inorganic chemicals, plastics, synthetic rubber, soaps, paints, industrial gases, fertilizers, pesticides, and pharmaceuticals. There are chemical plants throughout the United States, but the highest concentration is located near the supplies of energy and feedstocks—the oil and gas producing regions in Texas, Louisiana, and Oklahoma.

Chemical producers are the second largest energy-consuming industry. Natural gas is the principal fuel in most chemical production processes, but electricity plays a large role in the production of those agricultural chemicals, chloralkalies, and industrial gases that are produced electrolytically. Large quantities of natural gas and LPG are used as feedstocks. Natural gas (methane) is used as a feedstock in the production of ammonia (a major component of fertilizers), hydrogen, methanol, and carbon black. LPG are used in the production of many petrochemicals including ethylene, propylene, vinyl chloride, and styrene. Feedstocks account for about 34 percent of the chemical industry's energy use.[58]

Steam, used for process heating and pressurization purposes, consumes about 35 percent of the energy used in the chemicals industry. Because of this heavy use of steam, cogeneration is particularly attractive in this sector. An additional 13 percent of energy is used for direct process heating purposes such as fluid heating. Except in the industrial gases and chloralkalies industries, electricity use in chemicals production is dominated by pump, fan, compressor, and related mechanical drive needs. Materials movement is also a large use. Motor drive functions account for 16 percent of energy consumption.[59]

Chemical production is highly energy intensive because of the number and complexity of the process stages involved. Six of the most energy intensive processes are described in box 3-A. In 1988, the industry consumed about 11,600 Btu per dollar of product shipped, which was approximately double that of the manufacturing sector as a whole.[60] The high-volume, low-value bulk chemicals such as sulfuric acid, industrial gases, and ethylene are especially energy intensive to produce.

The chemical industry is composed of a very diverse group of industries. Each has its own particular energy needs and problems. Several of the larger chemical industries are profiled below to illustrate the many different issues and problems that are faced.

SULFURIC ACID[61]

Sulfuric acid is the most produced chemical in terms of tonnage. An inorganic chemical, it is used as a processing agent in industries such as phosphate fertilizer production, petroleum refining, chemicals production, and ore processing.

Sulfuric acid (H_2SO_4) produced by the contact process. Sulfur is burned in air to produce

---

[56] Alternatively, petroleum refineries' energy consumption could be reduced through the adoption of automobile engine technologies that have less strict fuel requirements.

[57] U.S. Department of Commerce, International Trade Administration *U.S. Industrial Outlook 1991* (Washington, DC: U.S. Government Printing Office, January 1991).

[58] Office of Technology Assessment estimates, based on data from the Industrial Sector Technology Use Model (ISTUM1), see table 2-3.

[59] Ibid.

[60] U.S. Department of Energy, *Manufacturing Energy Consumption Survey, Consumption of Energy 2988,* op. cit., footnote 31.

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

Box 3-A–Energy-Intensive Processes in Chemical Manufacturing

- Electrolytic processes in which electricity is used in direct chemical conversion.
- Fuel-heated reaction processes which require some type of heat to force a chemical reaction to take place. Energy sources include steam (except for high-temperature reactions), natural gas, residual fuel oil, distillate fuel oil, and even fluidized-bed coal combustion. Where precise temperature regulation is required, natural gas and distillate fuel oil are used.
- Distillation processes which involve evaporation and condensation to physically separate end products from feedstocks and/or byproducts.
- Refrigeration processes which involve compression and expansion of a refrigerant, such as ammonia or a fluorocarbon, to cool feedstocks or products below ambient temperatures.
- Evaporation processes which use passive-evaporation to cool feedstocks or products. in general, the evaporated water is lost to the atmosphere, and the heat energy is unrecoverable.
- Machine driven processes which are used to pump, compress, or move feedstock and end product materials. Machine drive arises from electric motors, steam turbines, or gas turbines. A subcategory of machine drive processes-mixing and blending (especially in polymerization processes)--can be very energy intensive due to the high viscosity of the materials.

SOURCE: U.S. Congress, Office of Technology Assessment, Industrial *Energy Use,* OTA-E-198 (Washington, DC: U.S. Government Printing Office, June 1983) adapted from Robert Ayres, *Final Report on Energy Consumption by Industrial Chemicals Industry,* DOE contract No. DE-ACO1-79CS40151, Oct. 7, 19S1.

sulfur dioxide (SO_2), then catalytically oxidized to SO_3, and finally absorbed in aqueous acid to form H_2SO_4. To meet SO_2 emissions regulations, most new plants use a double absorption process. Each of the three steps are exothermic, so modem acid plants are net energy producers. Most of the heat is recovered as steam and used in adjacent phosphoric acid plants. Small amounts of steam are also used for sulfur storage and melting. In some plants, the steam is run through steam turbine cogeneration units to produce electricity. The largest internal energy consumer in a sulfuric acid plant is the main blower (driven by steam turbine or electric motor) used to move the gases through the operation.

Great efforts have been made to maximize energy production from sulfuric acid production. The work has primarily centered on using waste heat to generate steam at higher pressure for use in cogeneration equipment. Additional energy can be produced by substituting low pressure steam for dilution water, using waste heat recovered from acid coolers (currently lost to cooling water), and using improved catalysts allowing lower “light-off’ temperatures and/or less dilution air.

Maximum energy efficiency corresponds to maximum electricity cogeneration. The profitability of this endeavor is affected greatly by local conditions, i.e., electricity price rates, proximity to steam users, and utility capacity profiles.

Currently, a typical double absorption process without extensive heat recovery can produce 14 percent more energy than the average technology being used (1988 data) (table 3-6). An advanced plant using the features described above with maximum electricity output to the grid could possibly produce 73 percent more energy than the current average technology. These efficiencies have been achieved at the pilot scale, but not yet demonstrated on a commercial scale.

Table 3-6-Energy Use by Selected Chemical Production Technologies

Process	Energy use (thousand Btu/ton of end product)		
	Current	State-of-the-art (2010)	Advanced (2010)
*Sulfuric **acid** (1988)b*			
Energy consumption	**232**	—	—
Export steam	**-2,093**	—	—
***Total* (net energy production)**	**-1,861**	**-2,117**	**-3,226**
Nitrogen and oxygen production (1985)c			
Separation,	**540**	**351**	**244**
Compression (80 percent of production)	**409**	**409**	**409**
Liquefaction (20 percent of production),	**1,720**	**1,720**	**1,720**
Electricity losses	**2,517**	**2,124**	**1,902**
Total	***3,728***	***3,146***	***2,818***
Ethylene (1988)			
Feedstock energy	**53,600**	**53,600**	**49,000**
Process energy	**4,600**	**3,800**	**3,400**
Total	58,200	57,400	52,400

aAverage of currently implemented tehnologies.

bFigures for Sulfuricaid are negative **because the production process is exothermic--it produces more energy than it consumes.**

cAssumes production of 58 percent nitrogen and 42 percent oxygen.

NOTE: Purchased electricity is counted at 10,500 Btu/kWh; generation and transmission losses are included. Estimated losses were approximately 117 thousand Btu/ton of sulfuric acid (1988) **and 2.5 million Btu/ton of oxygen and nitrogen (1985).**

SOURCE: Energetic Inc., *Industry Profiles: Chemicals,* **prepared for the U.S. Department of Energy, Office of Industrial Technologies, Report No. DE-ACO1-87CE40762, December 1990. Some data modified by the Office of Technology Assessment.**

NITROGEN AND OXYGEN[62]

Nitrogen and oxygen, the second and third highest tonnage chemicals, are used for a variety of purposes in industrial processes. Nitrogen is used variously as a purge gas (to prevent oxidation), pneumatic fluid, and cryogenic medium in the chemical, metals, food, and electronics industries. Oxygen is used as an oxidizing agent in steelmaking, nonferrous metals production, chemical and petrochemical production, and wastewater treatment. Transportation of these industrial gases is costly, so dedicated plants are commonly built right beside major consumers. Most nitrogen and oxygen is produced by the cryogenic distillation process. It is the most economical process for high-volume, high-purity production. Other production methods are cryogenic distillation, pressure-swing adsorption (PSA), membrane separation, and chemical-based processes.[63]

Cryogenic distillation-Air is first dried and cleaned of impurities, then liquefied, and finally separated into more the volatile nitrogen (boiling point -320°F or 77.4°K) and the less volatile oxygen (-297°F or 90.20K) in a rectifier. The double column air separation system is capable of providing both liquefied or gaseous oxygen and nitrogen. However, liquid production is kept to a minimum, because withdrawing the products in liquid form requires about three times as much power as comparable gaseous production and also reduces the rated capacity of the equipment.

---

[62] Ibid.

[63] Electric dissociation of water for hydrogen and oxygen production has very little Commercial importance.

Cryogenic distillation is a very energy-intensive activity. A great amount of electricity is used to drive the feed air compressor. On average, the industry uses about 15.7 kWper ton of oxygen produced each day (table 3-6). The energy consumption is broken up into three processes: separation, compression, and liquefaction. State-of-the-art and advanced technologies affect primarily the separation stage. A state-of-the-art plant uses 16 percent less energy than the average current technology. The remaining inefficiencies in these modem processes arise principally from non-idealities in the refrigeration process, thermal inefficiencies in heat exchangers, and losses of refrigeration through heat leaks. An advanced plant could possibly use 24 percent less energy than the current average.

Pressure swing adsorption--Air is separated by preferentially adsorbing either nitrogen or oxygen onto physical absorbents or molecular sieves. Older PSA units produced gas with purities in the 90 to 95 percent range and increased purity could only be realized by decreasing product output. New advances in absorbent materials now permit purities approaching that of cryogenic units. PSA is more efficient than cryogenic distillation, but is presently only economical for smaller, lower purity production applications.

Membrane separation-Air is separated through the differential diffusion of its constituent gases through a semipermeable membrane. Energy consumption is lower than in cryogenic distillation, but the economics depend primarily upon the cost and development of suitable membrane materials. Membranes are used mostly in small-scale separation units.

Chemical separation—The Moltex process produces 99.8 percent pure oxygen via a reversible chemical reaction of oxygen with molten alkali *nitrates* and nitrites. Though the chemical process uses 40 percent less energy than cryogenic distillation, its economics are only marginally better. Significant displacement of the mature cryogenic technology has yet to occur.

ETHYLENE[64]

Ethylene is the highest tonnage organic chemical produced in the United States. It is used principally as a building block for polymers (principally polyethylene) and other industrial chemicals, including ethylene dichloride, ethylbenzene, and ethylene oxide.

Production of ethylene occurs in four sections: 1) thermal cracking, 2) gas compression and treatment, 3) product separation, and 4) refrigeration. Thermal cracking of hydrocarbons in the presence of steam is the most widely used process. Cracking is done at about 2,900 F and 30 psia pressure, followed by rapid quenching to below l,760°F. Ethylene is recovered by low temperature fractionation at 500 to 550 psia and purified at about -85°F to remove hydrogen, methane, and ethane.[65]

About 90 percent of the energy used in the production of ethylene is consumed as feedstock. The common feedstocks are ethane and propane (from natural gas processing plants) and refinery gas, naptha, and heavy gas oil (from petroleum refineries). Use of heavier, oil-based feedstocks is increasing. Most new plants are designed to crack naptha or heavy gas oil and are flexible enough to crack either, depending on price and supply.

The main source of processing energy is the fuel used in cracking furnaces, principally to supply heat for the endothermic cracking reaction. Fuel use increases sharply with heavier feedstocks, although much of this energy is ultimately recovered from the flue gases and hot products.

On average, current plants consume about 29,100 Btu/lb of ethylene (26,800 feedstock and 2,300 processing energy) (table 3-6). State-of-the-art technologies such as PINCH-optimized refrigeration and heat integration systems can save

---

[64] *Energetic,* Inc., *Industry Profiles: Chemicals,* op. cit., footnote 61.

[65] "Ethylene," *McGraw-Hill Encyclopedia on Science and Technology (New* York, NY: McGraw-Hill, 1987).

PPG INDUSTRIES, INC.

An ethylene glycol production plant. Glycol is used for making polyester fibers, photo film, and plastic bottles.

about 17 percent of processing energy. Advanced technologies embodying even more heat integration and optimization and other improvements might yield another 9 percent improvement in processing energy and similar percentage improvements in feedstock energy.

EFFICIENCY[66]

In the 1980s, the chemical industry restructured itself by closing inefficient and obsolete plants, streamlining production processes, reorganizing corporate activities, and placing more emphasis on specialty chemicals with high profit margins. As a result, the chemical industry currently uses relatively state-of-the-art technologies. There remain, however, large opportunities for new cogeneration capacity.

Pulp and Paper[67]

Paper mills process cellulose fibers, primarily from wood, into writing paper, newsprint, magazine stock, paperboard, cardboard, sanitary tissues, and various other decorative and structural papers. The wood is first ground and pulped to separate the fibers from each other and suspend them in water. Later, the pulp is filtered onto wire screens, dried, and formed into paper. Along the way, the fibers may be beaten for strength, bleached for whiteness, or sized to improve their writing characteristics. There are five principle process steps in paper production: 1) wood preparation, 2) pulping, 3) bleaching, 4) chemical recovery, and 5) papermaking.

Wood fiber is the predominant ingredient in paper. However, trees cut specifically for paper manufacture provide only slightly more than half of the fiber used. The remaining fiber is secondary material obtained by recycling used newsprint, spent packaging, and other waste paper. The waste residues of lumber operations and wood chips from saw mills provide additional material.[68]

On average, about 35 million Btu are used to produce a ton of paper (based on 1988 data).[69] The most energy-intensive steps are the papermaking, pulping, and chemical recovery steps. Widespread adoption of state-of-the-art technologies can reduce energy consumption by an estimated 29 percent (tables 3-7 and 3-8) from current

---

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

[67] "Paper," *McGraw-Hill Encyclopedia on Science and Technology (New* York, NY: McGraw-Hill, 1987). "Paper," *The Academic American Encyclopedia, Online Edition* (Danbury, CT: Grolier Electronic Publishing, 1991). A. Elaahi and H.E. Lowitt, Energetic, Inc., *The U.S. Pulp and Paper Industry: An Energy Perspective,* prepared for U.S. Department of Energy, Office of Industrial Programs, Report No. DOE/RL/01830-T57 (Springfield, VA: National Technical Information Service, April 1988). Energetic, Inc., *Industry Profiles: Paper,* prepared for the U.S. Department of Energy, Office of Industrial Technologies, Report No. DE-AC01-87CE40762, December 1990.

[68] Fibers can also come from nonwood sources, including: esparto grass, bagasse (the plant residue left after the juice has been extracted from sugarcane), cereal and flax straws, reeds, cotton and linen rags, waste cotton from cotton mills, and various other plant sources. The choice of materials depends on the intended end use of the paper. *The Academic American Encyclopedia, Online Edition,* ibid.

[69] Energetic, Inc., Industry *Profiles: Paper,* Op. cit., footnote 67.

Table 3-7—Energy Use by Pulp and Paper Production Technologies

Process	Process mix			Measure	Energy use (million Btu/ton of product)			Product
	Current	State-of-the-art	Advanced		Current	State-of-the-art	Advanced	
	(1988)	(2010)	(2010)		(1988)	(2010)	(2010)	
Wodpreparation	0.71	0.71	0.71	tons of wood per ton of pulp	0.5	0.4	0.4	*wood*
Pulping								
Chemical: kraft	55.3	55.2	42.5	%pulp produced	8.3	4.9	4.4	Pulp
Chemical: sulfite	1.8	2.1	1.4	% pulp produced	8.6	6.3	5.7	Pulp
Chemical: other[b]	1.6	1.5	1.4	% pulp produced	16.0	8.8	7.9	Pulp
Semichemical: neutral sulfite	5.0	5.0	2.1	% pulp produced	9.8	7.2	6.5	Pulp
Mechanical: stone groundwood	2.0	2.1	—	% pulp produced	14.5	13.2	—	Pulp
Mechanical: refiner mechanical[c]	2.0	—	—	% pulp produced	18.6	—	—	Pulp
Thermomechanical	2.8	5.0	5.0	% pulp produced	19.7	15.8	15.8	Pulp
Chemimechanical	—	—	—	% pulp produced	—	14.5	—	Pulp
OPCO process	—	—	—	% pulp produced	—	—	12.6	Pulp
Non-sulfur process	—	—	10.6	% pulp produced	—	—	3.2	Pulp
Biological	—	—	5.7	% pulp produced	—	—	11.4	Pulp
Alcohol	—	—	2.1	% pulp produced	—	—	2.2	Pulp
Waste paper	19.6	20.4	20.4	% pulp produced	4.3	4.0	4.0	Pulp
Market pulp drying	9.9	8.7	8.7	% pulp produced	4.2	4.0	1.3	Pulp
Subtotal	1.11	1.13	1.13	tons of pulp per ton of paper	7.9	5.5	4.9	Pulp
Bleaching	*0.3*	0.3	0.3	fraction of pulp bleached	7,5	5.6	4.5	Pulp
Chemical recovery								
Kraft	55.3	55.2	42.5	% pulp produced	10.1	6.4	4.2	Pulp
Sulfite	1.8	2.1	1.4	% pulp produced	7.5	4.8	3.1	Pulp
Semichemical	5.0	5.0	2.1	% pulp produced	6.0	3.8	2.5	Pulp
Subtotal	0.62	0.62	0.46	fraction of pulp with a chemical recovery stage	9.7	6.1	4.1	Pulp
Papermaking								
Newsprint	7.6	8.0	8.0	% paper produced	8.2	5.5	3.7	Paper
Printing and writing paper	27.8	30.1	30.1	% paper produced	13.8	9.3	5.6	Paper
Industrial paper	6.4	4.0	4.0	% paper produced	14,1	9.5	5.7	Paper
Tissue paper	7.0	7.3	7.3	% paper produced	11.2	8.3	8.3	Paper
Paperboard	37.5	37.6	37.6	% paper produced	13.6	9.2	5.5	Paper
Recycled paperboard	11.2	11.3	11.3	% paper produced	13.6	9.2	5.5	Paper
Construction paper	2.4	1.7	1.7	%. paper produced	12.7	8.6	5.1	Paper
Subtotal	1.00	1.00	1.00	ton of paper	13.1	8.9	5.6	Paper
Auxiliary equipment								
Lighting, space heating, and power plant	1.00	1.00	1.00	ton of paper	2.9	2.7	2.7	Paper
Total	1.00	1.00	1.00	ton of paper	34.5	24.6	18.0	Paper

a Average of currently implemented technologies.

b Chemical processes for dissolving pulps and alpha pulps.

c For state-of-the-art, refiner mechanical pulping is assumed to be replaced by thermomechanical pulping with heat recovery.

NOTE: Purchased electricity is counted at 10,500 Btu/kWh; generation and transmission losses are included. Estimated losses in 1988 were approximately 4.3 million Btu per ton of paper.

SOURCES: A. Elaahi and Howard E. Lowitt, Energetic, Inc., *The* U.S. *Pulp and Paper Industry: An Energy Perspective,* prepared for the U.S. Department of Energy, Office of Industrial Programs, Report No.DOE/RL/01830-T57 (Springfield, VA: National Technical Information Service, April 1988). Energetic Inc., *Industry Profiles: Paper,* prepared for the U.S. Department of Energy, Office of Industrial Technologies, Report No. DE-AC01-87CE40762, December 1990.

Table 3-8-Major Energy Saving Features of Improved Pulp and Paper Production

Process	State-of-the-art	Advanced
Pulping		
Chemical	Continuous digesters for large units. (S) Displacement heating for small units. (S)	Alcohol-based solvent pulping. (S) Biological pulping in which enzymes cause designation reactions to occur at ambient temperatures. (M)
Mechanical	Thermomechanical pulping with heat recovery. (s)	Non-sulfur chemimechanical pulping. (S) OPCO pulping process (sodium sulfite-based). (s)
Bleaching	Displacement bleaching. (S) Oxygen bleaching in the first extraction stage. (M)	Biobleaching in which biological enzymes replace bleaching chemicals. (S)
Chemical recovery	Waste-heat recovery technologies in lime kiln, including: chain systems to enhance heat transfer; lime product coolers to preheat combustion air; and flash dryers to predry the lime mud. (S) Turbumix system, whereby lime mud is mixed in the gas flow to create a fully turbulent flow. (S) Tampella Recovery System. (M) Multiple-effect falling-film evaporators for black liquor evaporation and concentration. (M) Vapor recompression evaporation of black liquor. (M)	Freeze concentration of black liquor (presently not economical). (S) Black liquor gasification in a combined cycle cogeneration system. (M) Black liquor hydropyrolysis. (M) Black liquor dry pyrolysis. (M) NSP process, uses a cyclone gasifier to process solids prior to firing the pyrolysis gases in a boiler. (M)
Papermaking		
Forming	Top-wire (hybrid) formers. (M)	
Pressing	Increased water removal through: extended nip press; higher nip pressures; wider nips (longer residence time); use of steam boxes in press section; and upgrade of clothing and auxiliary equipment. (M) Hot pressing using one or more steam showers to heat water in the sheet. (M)	Displacement pressing. (M)
Drying	Reduced air heating by using enclosed hoods and countercurrent flow of air and product. (M) Infrared moisture profiling. (M)	Impulse drying. (S)
Auxiliary processes and process control	Use of boiler waste heat in bark dryers. (M)	Total mill automation and information system. (M) New sensors and expert systems.

KEY: (S) = significant savings, 50 to 100 percent of energy used in particular process; (M) = moderate savings, 25 to 50 percent of energy used in particular process.

SOURCE: A. Elaahi and Howard E. Lowitt, Energetic, Inc., The *U.S. Pulp and Paper Industry.' An Energy Perspective,* prepared for the U.S. Department of Energy, Office of Industrial Programs, Report No.DO13RU01830-T57 (Springfield, VA: National Technical Information Service, April 1988).

average practices. The potential reductions are greatest for the papermaking stage. Advanced technologies, not yet commercialized, could possibly reduce energy use an additional 27 percent.

WOOD PREPARATION

Paper production begins with wood preparation, which consists of removing the tree bark and chipping the wood into small pieces. This process requires comparatively little energy.

PULPING

Pulping breaks apart the fibers in the wood and cleans them of unwanted wood residues. The principal pulping methods use chemical techniques, mechanical techniques, or a combination of the two. Chemical pulping techniques account for 80 percent of U.S. production. Each pulping method involves tradeoffs in terms of cost, yield, and paper quality.

In chemical pulping, the wood chips or other fibrous materials are cooked in an aqueous solution at high temperature and pressure. Steam provides the heat and pressure in the cooking vessel (digester). The kraft process, the most widely used pulping technique, uses a solution of sodium hydroxide and sodium sulflde. The sulfite process uses a sodium sulfite solution. Cooking times may be as long as 12 hours. The cooked pulp is then washed to remove the chemicals and screened to separate out undigested wood knots and other unwanted materials.

Chemical processes dissolve most of the lignin (the “glue” that holds the fibers together), and much of the hermicellulose, and leave the cellulose fibers relatively undamaged. The absence of lignin and the relatively minor physical damage done to the fibers results in strong, high-quality paper that can be bleached to high brightness. However, the yield is only 40 to 60 percent of the dry weight of the wood, because the lignin and other components are removed.

In mechanical pulping, the cellulose fibers are torn apart by pressing logs against wet grindstones or by passing wood chips between counterrevolving grooved metal disks -(refiners). The lignins and other residues are not removed, so the yield may be nearly 95 percent of what was originally in the tree. However, the fibers are broken and damaged by the mechanical processes. The shorter, weaker fibers and the presence of lignin makes this pulp appropriate for less expensive grades of paper, such as newsprint.

Combining mechanical methods with chemical and/or steam treatments produces pulps of varying yields and quality. In thermomechanical pulping (TMP), wood chips are softened with steam before they are refined. This produces paper that is significantly stronger than that from mechanical pulp, but still weaker than that from chemical pulps, with only a small sacrifice in yield. In chemical thermomechanical pulping, the wood is treated with both chemicals and steam before refining. This produces a still stronger pulp. Lastly, semichemical pulping uses even more chemicals, but not enough to render the mechanical stage unnecessary.

Technologies that integrate fermentation into the conventional pulping process can offer also energy savings. They include biopulping using enzymes derived from wood rot funguses, chemial pulping with fermentation and black liquor phase separation, and ethanol organosolv pulping. Energy savings of 28 percent in the pulping process using enzymes compared with mechanical techniques have been demonstrated in Sweden.[70] Currently, pulping cycles using these techniques are too slow for commercial application. A substantial amount of research is still needed for each of these processes.

Pulping accounts for 26 percent of the energy used in pulp and paper production. State-of-the-art technologies such as continuous digesters, displacement heating, anthraquinone pulping, and increased use of thermomechanical pulping

---

[70] A. Elaahi and H.E. Lowitt, op. cit., footnote *67.*

with heat recovery and cogeneration can reduce the energy use of this stage by about 26 percent from current average practices. Advanced technologies could possibly reduce energy use an additional 10 percent.

BLEACHING

Most pulps are relatively dark in color. Bleaching whitens the pulps for use in writing, printing, and decorative papers. Various grades of paper require different levels of treatment. Writing paper requires a full bleaching; newsprint requires only a light treatment; and corrugated cardboard generally needs no bleaching. The process must be carefully controlled so that the cellulose fibers are not weakened.

Bleaching brightens paper by altering and/or removing the lignin, which causes the dark color of pulp. Chemical pulps, which contain low concentrations of lignin, are bleached by breaking up the lignin and removing it. This is accomplished with alternating treatments of oxidizing agents (chlorine, chlorine dioxide, hypochlorite, hydrogen peroxide, and oxygen) and alkali solutions (sodium hydroxide). Sulfite pulps are generally lighter in color than kraft pulp and therefore need less bleaching. They require no bleaching at all when used in newsprint. High-yield, mechanical pulps are treated with hydrogen peroxide or sodium hydrosulfite to reduce the light absorption of lignin without dissolving it.

Bleaching uses about 7 percent of the energy used in paper production. State-of-the-art technologies such as displacement bleaching can reduce the energy use at this stage by about 30 percent from current average practices.

CHEMICAL RECOVERY

The kraft and sulfite processes use large quantities of chemicals to separate the cellulose fibers. Regenerating these chemicals for reuse is important for economic and waste disposal reasons. When the chemicals are recovered, enough energy is extracted from the wood byproducts to make many paper mills self-sustaining with respect to energy.

Chemical pulping processes produce waste streams of black liquor, which contains spent chemicals and wood residues. Black Liquor is concentrated in evaporators and then burned in boilers, many of which are connected to steam turbine cogeneration systems. The wood residues fuel the boiler and the spent process chemicals remain behind as smelt at the bottom of the boiler furnaces. This smelt is treated with lime to convert the sodium carbonate back into sodium hydroxide. The lime is then itself regenerated by being burned in lime kilns. Sodium sulfide, the other major chemical in the kraft process, is also recovered from the smelt. The relatively small quantities of chemicals lost during processing are made up by adding sodium sulfate, which is either purchased or recovered from the manufacture of bleaching chemicals.

Chemical recovery accounts for 19 percent of the energy used in paper production. State-of-the-art technologies such as waste heat recovery units and turbomix systems can reduce the energy use of this stage by 37 percent from current average practices. Advanced technologies could possibly reduce energy use an additional one-third.

PAPERMAKING

The papermaking stage consists of stock preparation (beating), sheet forming, pressing, and drying. Before the fibers are formed into sheets, they go through a mechanical pounding and squeezing process called beating to make them more flexible, thereby increasing their matting, or felting, capacity. Pigments or dyes are added to the pulp at the beating stage, along with filler materials that help preserve the paper or give it a better opacity and finish. Sizing materials may be added to improve the “feel” and printability of paper.

Once prepared, the pulp is formed into paper sheets. The fibers are deposited in a sheet on a screen, drained and pressed to remove the bulk of the water, and then dried. The two most common papermaking machines in current use are the

Fourdrinier and the cylinder machine. Both are continuous processes. In the Fourdrinier, the pulp-and-water mixture is dispersed at a controlled rate through a headbox onto a moving wire-mesh screen. As the screen moves away from the headbox, various suction devices drain the water from the pulp, leaving a sheet of matted pulp that still contains a high proportion of water. The sheet then moves on to a woolen felt screen, which takes it through a series of presses, where more water is removed. Finally, the sheet passes over a number of heated drums that evaporate the remaining water. Many new papermaking machines incorporate two moving wire-mesh screens between which the pulp is pumped, and water is extracted from both sides. The ‘‘twin-wire’ machine produces a paper that is practically identical on both sides, an important property for printing papers.

The cylinder machine differs from the Fourdrinier principally in the “wet end, ” or forming operation. Instead of the moving wire screen, a screen-covered rotary cylinder is half-submerged in the pulp vat. As the cylinder rotates, a sheet of matted pulp is formed on its exterior surface and then picked up by a moving belt, where it is treated to remove the remaining water, as in the Fourdrinier process. A series of cylinders maybe used, each one depositing an additional layer of pulp on the belt, so that multilayer sheets are built up to make thick papers and paperboard.

Upon leaving the paper-forming machine, the dried paper is wound onto large reels, slit to the required widths, cut into sheets, trimmed, and then packaged. In some cases, the paper is calendared or coated. It may also be converted into bags, boxes, corrugated shipping paper, and other products.

Papermaking is the largest energy consuming process of the mill. It accounts for 38 percent of the energy used in paper production. The most energy-intensive activities are drying (65 percent of papermaking energy use) and stock preparation (30 percent).

Energy Use (million Btu per ton of paper)

	Current average	State-of-the-art
Stock preparation.	3,4	2.8
Sheet formation.	0.3	0.1
Pressing.	0.3	0.3
Drying.	7.4	4.4

State-of-the-art technologies such as top-wire formers and improved mechanical and thermal water removal techniques can reduce the energy use of this stage by about 32 percent. Improved presses (e.g., the extended nip press), used to squeeze the water out of the paper before drying, reduce energy use and also improve fiber-to-fiber bonding, resulting in higher strength and higher quality sheet. Advanced technologies, such as impulse drying, could possibly reduce energy use an additional 27 percent.

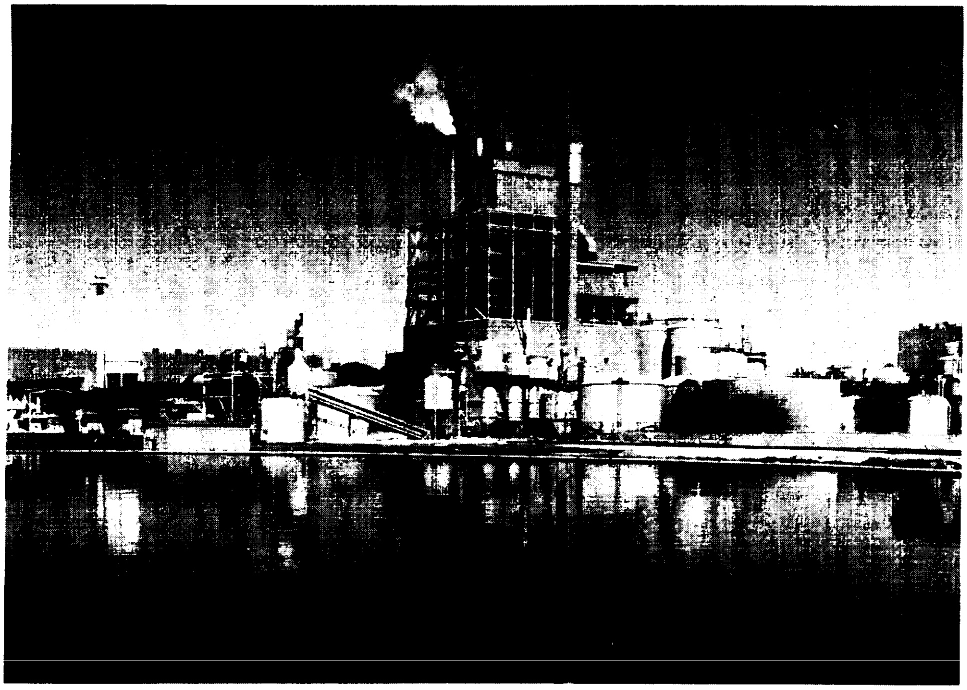
WASTE STREAM ENERGY

There is a great amount of energy embedded in the waste products of the paper industry. Wood wastes and residues supply the heat and electricity required for pulping, bleaching, drying, and evaporating the spent black liquor. If the harvesting waste and the bark are also burned to produce energy, and if water is conserved by countercurrent washing of the pulp, a bleached kraft pulp mill can be self-sufficient in energy .71

The typical pulp and paper operation has three principal waste streams that can provide energy: hog fuel, black liquor, and forest residues. Hog fuel is the bark, sawdust, and other scrap produced in reducing logs to feedstock for the pulping process. Hog fuels can supply about 2.6 million Btu/ton of pulp produced. Black liquor, from the chemical pulping process, an average energy content of about 11.2 million Btu/ton of pulp. Other residues are currently left in the forest when harvesting the trees. A portion of these

---

[71] “Paper,” *McGraw-Hill Encyclopedia on Science and Technology,* op. cit., footnote 67.


INTERNATIONAL PAPER CO.

A recovery boiler at a pulp and paper mill. Such a boiler can meet a significant portion of a mill's energy needs by burning waste from the pulping process.

forest residues might be collected. However, the technical, economic, and environmental difficulties in using forest residues are significant. For example, the long term effects on forest soils would need to be examined closely. If fully recovered, the estimated energy content of forest residues would be about 21.5 million Btu/ton of pulp. Combined, these energy resources could provide 35.3 million Btu/ton of pulp.[72]

Most kraft pulp mills currently use their black liquor for cogenerating steam and electricity onsite. High-efficiency, steam-injected gas turbine or combined cycle technologies might be able to generate as much as 4,000 kwh of electricity per ton of pulp produced if all of the hog fuel, black liquor, and recoverable forest residues were used. Onsite electricity needs are typically about 740 kWh/ton of paper, so there would be a substantial amount of power that could be sold to the grid.

RECYCLING

Waste paper recycling is growing and may be a source of further energy savings. According to the Environmental Protection Agency (EPA), paper and paperboard recycling totaled 18.4 million tons in 1988, a recovery rate of 25.6 percent. This compares to a recovery rate of 16.7 percent in 1970.[73]

Recycling reduces the energy used in the paper production process and also in the harvesting and transport of the timber. However, these energy savings are offset somewhat by the energy needed to collect, transport, and de-ink the waste paper.

---

[72] Eric D. Larson, "Prospects for Biomass-Gasifier Gas Turbine Cogeneration in the Forest Products Industry: A Scoping Study," Princeton University, Center for Energy and Environmental Studies Working Paper No. 113.

[73] U.S. Environmental Protection Agency, *Characterization of Municipal Solid Wrote in the UnitedStates: 1990 Update*, EPA/530-SW-90-042, June 1990, pp. ES-7, 11.

Table 3-9—Estimated Energy Used To Produce Virgin and Recycled Paper and Paperboard Products (million Btu/ton produced)

	From 100% virgin wood	From mixed recycled paper		
Product	Energy use	Minimum virgin fiber content (percentage)	Energy use	Change due to recycling (percentage)
Paper products				
Newsprint	44.33	0	34.76	-21.6
Printing paper	67.72	16	43.43	-35.9
Packaging paper	47.07	70	43.48	-7.6
Tissue paper	68.52	0	29.46	-57.0
Paperboard products				
Liner board	14.46	75	*36.28*	+150.9
Corrugated board	37.22	0	*36.28*	-2.5
Box board	25.97	0	*36.25*	+39.6
Food service board	29.19	100	NA	—
Other paper board	17.65	0	36.32	+105.8
Construction board	31.71	*65*	32.24	+1.7

SOURCE: T. Gunn and B. Hannon, "'Energy Conservation and Recycling in the Paper Industry," *Resources and Energy 5:243-260, 1983.*

Estimates of energy used to produce paper and paperboard products from virgin wood and recycled paper are shown in table 3-9. Paper and paperboard mills are the major consumers of secondary fiber.

MATERIALS PRODUCTION

■ Steel

Steel products are produced from iron ore and iron scrap using a variety of pyrometallurgical, electrolytic, and mechanical processes. Integrated mills rely mostly on ore-based processes, the most common of which involves reducing pelletized iron ore into pig iron using coke (in a blast furnace); refining the iron into steel (in a basic oxygen furnace); and casting, forming, and treating the steel into sheet, bars, beams, and other products. The major steps are: ore preparation, cokemaking, ironmaking, steelmaking, primary casting, secondary finishing, and heat treating. Minimills usually produce steel from scrap, not iron, in an electric arc furnace. This method is also employed at some integrated mills. The process does not include ore preparation, cokemaking, and ironmaking, but does involve many of the same casting and forming steps. Over the last several decades, scrap-based steelmaking capacity has grown relative to ore-based capacity. However, in recent years, the U.S. industry's production has been relatively stable at 63 percent ore-based and 37 percent scrap-based.

The most energy-intensive steps are ironmaking and electric steelmaking. Reductions in energy intensity can result from shifts in the mix of processes, improvements in the efficiency of the processes, and improvements in yields. Currently, about 22 million Btu are used on average to produce a ton of finished steel (based on 1990 and 1991 data) .74 Energetic and the International

---

[74] The U.S. steel industry used 27.4 million tons of metallurgical coal (733 trillion Btu), 1.3 million tons Of steam coal (28 trillion Btu), 5.2 million tons of purchased coke (127 trillion Btu), 35.2 billion kWh of electricity (370 trillion Btu based on a conversion factor of 10,500 Btu/kWh), 244 million gallons of fuel oil (35 trillion Btu), and 368 billion cubic feet of natural gas (380 trillion Btu) to produce 78.9 million tons of steel products in 1991. The technology mix was 60.0 percent basic oxygen furnace (BOF), 38.4 percent electric arc furnace (EAF), and the remainder open hearth furnace (OH). The American Iron and Steel Institute, *Annual Statistical Report*, (Washington, DC: 1991).

Iron and Steel Institute (IISI) have estimated the energy intensity of state-of-the-art operations for the major production methods:

Energy intensity (million Btu per ton of finished steel)	Energetics75 estimate	IISI76 estimate
Basic oxygen furnace method (BOF)	16.1	19.077
Electric arc furnace method (EAF)	10.2	8.0
Average based on a 60:40 ratio of BOF and EAF production	13.8	14.6

Details of the Energetic estimates are shown in tables 3-10 and 3-11. Widespread adoption of state-of-the-art technologies can reduce energy consumption by about 34 to 38 percent from current average practices. Advanced technologies, not yet commercialized, could possibly reduce energy use an additional 13 percent.

ORE PREPARATION

Iron ore is prepared by being crushed and ground and then agglomerated (via pelletizing or sintering) into marble sized pieces that can be fed into a blast furnace. Ore preparation uses about 0.7 million Btu/ton of pellets or sinter produced. Use of state-of-the-art technologies, such as organic or cold bonding for pelletizing, can reduce energy use by about 18 percent from current average practices. If direct ironmaking and/or steelmaking, which are advanced technologies, become commercially available, the pelletizing and sintering operation may possibly not be needed.

COKEMAKING

Coke is produced by heating high-grade (metallurgical) coal to temperatures of 1,650 to 2,0000F for 12 to 18 hours. This boils off volatile compounds and leaves an 80 to 90 percent pure carbon product. Traditionally the chemical reactions in the coke ovens were stopped by quenching the coke with water and venting the steam into the atmosphere. A much more efficient technique is dry coke quenching, in which a nonoxidizing gas is circulated through the ovens to stop the chemical reactions and, at the same time, capture the heat from the coke to generate steam or electric power. This process also improves coke quality and reduces environmental emissions.[78]

The efficiency of converting coal to coke has improved substantially in recent years. The average amount of energy used to produce a ton of coke declined from 6.1 million Btu in 1980 to 3.5 million Btu by 1989.[79] State-of-the-art technologies, such as dry quenching and oven-gas heat recovery can lower this by about 14 percent. If direct ironmaking and/or steelmaking are commercialized, the coking operation will no longer be needed.

The high costs of environmental compliance have made coke ovens expensive to operate. The Clean Air Act of 1990 may force the closure of many U.S. coke facilities. In the short term, this will probably lead to greater importation of coke and more scrap-based steelmaking. In the longer term, coke may be rendered unnecessary by direct ironmaking and/or direct steelmaking. Indeed, the costs and environmental problems of cokemaking are a major force behind the efforts to develop direct ironmaking and steelmaking technologies.

---

[75] Energetics, Inc., *Industry Profiles: Steel,* prepared for the U.S. Department of Energy, Office of Industrial Technologies, Report No. DE-AC01-87CIM0762, December 1990.

[76] International Iron and Steel Institute, *Energy and the Steel Industry,* Brussels, 1982.

[77] This is Case A, commercially proven technologies, rather than the IISI base case.

[78] Jonathan p, Hicks, "The Search for a Cleaner Way to Make Steel, ' *The New York Times, Mar. 21, 1990,* p. D7.

[79] Energetic, Inc., In&m-y *profiles: Steel,* op. cit., footnote 75.

Table 3-10--Energy Use by Steel Production Technologies

	Process mlx				Energy use (million Btu/ton of product)			
	Current	State-of-the-art	Advanced	Tons input per ton	Current	State-of-the-art	Advanced	
Process	(1989)	(2010)	(2010)	output or percent	(1983)	(2010)	(2010)	Product
Agglomeration								
Pelletizing.	1.11	1.11	1.11	Pellets/pig iron	0.4	0.2	0.2	Pellets
Sintering.	0.38	0.38	0.38	Sinter/pig iron	1.5	1.2	1.2	Sinter
Cokemaking.	0.54	0.54	0.54	Coke/pig iron	6.0	3.0	3.0	
Ironmaking.	0.85	*0.85*	0,85	Pig iron/BOF steel	13.9	10,2	10.2	iron
	0.66	—	—	Pig iron/OH steel	13.9	—	—	Iron
Steelmaking								
Basic oxygen furnace (BOF). . . .	59.6	*62.0*	31.0	percent	0.5	-0.1	-0.1	BOF steel
Open hearth (OH).	4.5	—	—	percent	3.3	—	—	OH steel
Electric arc furnace (EAF).	35.9	*38.0*	38.0	percent	6.3	5.0	5.0	EAF steel
Direct steelmaking.	—	—	31.0	percent	—	·	9.9	Direct steel
Raw steel production, subtotal								
Ore/coke/iron/BOF route.	—	—	—	—	15.9	10.5	10.5	BOF steel
Ore/coke/iron/OH route.	—	—	—	—	15.2	—	—	OH steel
Scrap/electric furnace route.	—	—	—	—	6.3	5.0	5.0	EAF steel
Direct steelmaking route.	—	—	—	—	—	—	9.9	Direct steel
Average.	1.00	1.00	1.00	Ton of raw steel	12.4	8.4	8.2	Raw steel
Primary casting								
ingot casting.	35.1	5.0	5.0	percent	2.7	0.7	0.7	Cast steel
Continuous casting.	64.8	95.0	27.0	percent	1.0	0.2	0.2	Cast steel
Strip casting.		—	68.0	percent	—	·	b	Cast steel
Average.	0.91	0.94	0.94	Cast steel/raw steel	1.6	0.3	0.1	Cast steel
Forming, finishing, heat treating, and annealing								
Sheet/strip: hot rolled.	21.1	21.1	—	percent	2.5	1.5	—	Finished steel
Sheet/strip: cold roiled.	37.9	37.9	—	percent	6.2	3.8	—	Finished steel
Heavy plate.	9.0	9.0	—	percent	3.2	2.4	—	Finished steel
Sheet/strip: hot rolled (strip cast).	—	—	21.1	percent	—	—	0.7	Finished steel
Sheet/strip: cold rolled (strip cast).	—	—	37.9	percent	—	—	1.6	Finished steel
Heavy plate (strip cast).	—	—	9.0	percent	—	—	1.0	finished steel
Shapes and rails.	6.7	6.7	6.7	percent	4.4	1.9	1.9	Finished steel
Bars/wire rods.	25.3	25.3	25.3	percent	5.0	2.7	2.7	Finished steel
Average.	0.91	0.94	0.94	Finished steel/raw steel	4.7	2.8	1.7	Finished steel
Unallocated energyc.		—	—	—	1.9	1,8	1.6	Raw steel
Total.		—	—	—	20.1	13.1	11.5	Raw steel
					22.2	13.9	12.2	Finished steel

---

a Average of currently implemented technologies.

b All energy use for direct strip is charged. appropriate forming and finishing processes; hot and cold rolled sheet/strip and heavy plate.

[c] Includes galvanizing, electrolytic tinning, fuel-fired boiler operations, power generation services, and other miscellaneous services.

KEY: BOF - basic oxygen furnace; OH - open hearth furnace; EAF - electric arc furnace.

NOTE: Purchased electricity is counted at 10,500 Btu/kWh; generation and transmission losses are included. Estimated losses in 1989 were approximately 3.0 million Btu/ton of raw steel.

SOURCES: Sayed A. Azimi and Howard E. Lowitt, Energetic, Inc., *The U.S. Steel Industry: An Energy Perspective,* prepared for the U.S. Department of Energy, Office of Industrial Programs, Report No. DOE/RL/01830-T55 (Springfield, VA: National Technical Information Service, January 1988). Energetic Inc., *Industry Profiles: Steel,* prepared for the U.S. Department of Energy, Office of Industrial Technologies, Report No. DE-AC01-87CE40762, December 1990. F.T. Sparrow, Argonne National Laboratory, *Energy and Materials Flows in the Iron and Steel Industry,* Report No. ANL/CNSV-41 (Springfield, VA: National Technical Information Service, June 1983). J.B. Darby, Jr. and R.M. Arons, Argonne National Laboratory, *Energy and Materials Flows in the Fabrication of Iron and Steel Semifinished Products,* Report No. ANL/CNSV-8 (Springfield, VA: National Technical Information Service, August 1979). Some data modified by the office of Technology Assessment.

Table 3-1 l—Major Energy Saving Features of Improved Steel Production

Process	State-of-the-art	Advanced
Agglomeration		Stage discontinued, made obsolete by direct steelmaking.
Pellitizing	Peridur organic bonding process. (S) Cold bonding processes. (S)	
Sintering	Combustion air preheat. (M) Raw materials preheat. (M) Steam or power generation using sinter cooler offgases. (M)	
Cokemaking	Dry quenching. (S) Coke oven gas heat recovery. (S)	Stage discontinued, made obsolete by direct steelmaking.
Ironmaking		Stage discontinued, made obsolete by direct steelmaking.
Blast furnace	Top gas pressure recovery. (S) Hot stove waste heat recovery. (M) Wurth charging top; improves distribution of ore, coke, and limestone.	
External desulfurization	Added process between the blast furnace and the steelmaking stage. Decreases coke consumption by reducing the sulfur removal function of the blast furnace. (S)	
Steelmaking		
Open hearth (OH)	Discontinued use of open hearth steel furnace.	
Basic oxygen furnace (BOF)	In-process control of temperature and carbon content. (S) BOF offgas heat recovery. (M) Combined top and bottom oxygen blowing. (M)	Replacement of BOF steelmaking with direct steelmaking.
Electric arc furnace (EAF)	Scrap preheating. (S) Ultra high power transformers. (M) Bottom tap furnaces. (M) Water cooled furnace panels and top. (M)	
Secondary refining	Ladle metallurgy techniques, including: vacuum arc decarburization, argon stirring, and injection systems for desulfurization. (S) Specialty and stainless steel processes, including: electroslag remelting, argon-oxygen decarburization, vacuum induction melting, electron beam melting, and vacuum arc remelting. (S)	
Auxiliary processes	Ladle drying and preheating. (S)	

Primary casting	**Greater use of continuous casting.**	**Replacement of continuous casting by direct thin strip casting for hot and cold rolled sheet/strip and heavy plate products; combines primary casting and finishing and. forming stages.**
Continuous casting	**Modern casters. (S)** **Slab heat recovery. (S)**	
Ingot casting	**Soaking pit utilization and pit vacant time. (M)**	
Forming and finishing		
Reheating	**Direct roiling of sheet/strip; eliminates need for reheat furnace. (S)** **Reheat furnace waste heat recovery. (S)** **Reheat furnace insulation improvements. (M)** **Hot charging of products into reheat furnace. (M)**	**Replacement of continuous casting by direct thin strip casting for hot and cold rolled sheet/strip and heavy plate products; combines primary casting and finishing and forming stages.**
Pickling	**Insulated floats for steam savings. (M)**	
Annealing	**Continuous annealing. (S)** **Batch annealing air preheat. (M)**	
Cold rolling	**Continuous cold rolling. (S)**	
General	**Computerized** process control. **Increased combustion efficiency.** **(5 percent improvement over current practice).**	**Computerized process control.** **Increased combustion efficiency.** **(15 percent improvement over current practice).**

KEY: (S) = significant savings, impact on total operation greater than 200,000 Btu/ton; (M) = moderate savings, impact on total operation less than 200,000 Btu/ton.

SOURCE: SayedA. Azimi and Howard E. Lowitt, Energetic, Inc., *The U.S. Steel Industry:An Energy Perspective,* prepared for the U.S. Department of Energy, Office of Industrial Programs, Report No. DOE/RI/O1830-T55 (Springfield, VA: National Technical Information Service, January 1988).

IRONMAKING

Blast furnaces are the most common technology used to convert iron ore into iron.[80] Pelletized or sintered ore are fed into the top of the blast furnace together with coke and limestone and/or dolomite. Heated air (sometimes combined with natural gas or fuel oil) is blown into the blast furnace from the bottom. The burning coke heats, chemically reduces, and melts the iron ore.[81] The limestone and dolomite combines with impurities in the iron to form a slag that is removed at the end of the process. The pig iron produced by blast furnaces varies in composition depending on the ore and coke used, but typically consists of iron (92 percent), carbon (4 percent), manganese (2

---

[80] An alternative technique is the direct reduction of iron ore to metallic iron using natural gas. Direct reduced iron (DRI), also called sponge iron, is suitable for steelmaking using electric arc furnaces. This technology is used extensively in areas such as Venezuela, Mexico, and Indonesia, where natural gas is abundant and inexpensive, but is relatively rare in the United States.

[81] The coke serves three purposes in the ironmaking stage: as a reducing agent to convert the ore (iron oxide) into pig iron; as fuel to heat and melt the ore/iron; and to physically support the ore within the blast furnace. To meet these needs, coke must have a low impurity and ash content and be physically strong. Coke is produced from a higher grade coal than is used for steam and electricity generation applications.

percent), silicon (1 percent), and small amounts of other elements.

Ironmaking currently uses on average about 13.9 million Btu/ton of iron ore produced. It accounts for about half of the energy used in an average integrated mill, using the basic oxygen steelmaking process. State-of-the-art technologies such as top gas pressure recovery and external desulfurization can reduce the energy use of this stage by 27 percent from current average practices. Top gas pressure recovery turbines can be used to generate 8 to 15 MW of power using the pressure and heat from the blast furnace. External desulfurization of pig iron is an added process between the blast furnace and the steelmaking stage. It lowers coke consumption by decreasing coke's role in removing sulfur from the melt in the blast furnace. If direct steelmaking is commercialized, the ironmaking operation will no longer be needed.

There are several direct ironmaking technologies under development that could decrease energy consumption at this stage. One of the primary goals of these development efforts is to produce iron with coal, rather than with coke.[82] By eliminating the coke ovens and agglomeration facilities, mills based on these new technologies would have substantially lower capital costs than similarly-sized conventional plants. The U.S. Department of Energy, as part of its Metals Initiative, is conducting research into an advanced ironmaking technology that has such benefits, plus it is tailored to domestic taconite (iron ore) supplies. Among the new ironmaking technologies are the plasmared, Korf Reduction, plasmasmelt, inred, and elred processes. Energy requirements for these systems range from about 11.4 million Btu/ton of hot metal for three-stage systems to as much as 25.8 million Btu/ton for single-stage systems. The low end of these energy requirements is about 10-percent better than what typical conventional blast furnaces achieve and about 5 percent better than what the best cost effective blast furnace technology available today achieves. The high end of the direct ironmaking energy requirements is however, much higher than conventional best practice technologies achieve today.[83] The potential capital savings and other advantages may push direct coal-based processes into a dominant role in the steel industry of the future.

STEELMAKING

Steelmaking refines the pig iron, scrap, or, in some cases, direct reduced iron (DRI). The purpose of the process is to remove most of the impurities such as carbon, phosphorus, sulfur, and silicon from the melt, and to add the necessary alloying elements such as manganese, molybdenum, chromium, and nickel.

Two types of furnaces are commonly used to produce steel: the basic oxygen furnace (BOF) and the electric arc furnace (EAF).[84] Basic oxygen furnaces are used in plants that produce finished steel from iron ore. The iron is refined into steel by blowing oxygen into the furnace. The oxygen reacts with the carbon in the iron melt to produce carbon monoxide. The evolving gas removes carbon from the melt and vigorously boils the melt to accelerate other refining reactions. The oxygen also reacts with silicon and various other elements in the melt to form a slag, which is later separated from the steel.

The carbon-oxygen reaction is exothermic (produces heat) and theoretically needs no external energy to run. To absorb excess heat produced by the reaction, about 30 percent of the iron charge to a BOF is scrap, which contains little

---

[82] U.S. Congress, Office of Technology Assessment, *Fueling Development: Energy Technologies for Developing Countries*, op. cit., footnote 12.

[83] R.B. Smith and M.J. Corbett, "Coal-Based Ironmaking," *Ironmaking and Steelmaking*, vol. 14, No. 2, 1987, pp. 49-75.

[84] A third technology, the open hearth furnace, was made obsolete by the basic oxygen furnace. The last open hearth facility in the United States was closed in 1991.

carbon to react with oxygen. In practice, BOFs consume 0.5 million Btu/ton of raw steel produced. State-of-the-art BOFs equipped with in-process control of temperature and carbon content, offgas heat recovery, and combined top and bottom blowing generate about 0.1 million Btu of excess energy for each ton of raw steel produced.

Electric arc furnaces are used primarily to refine recycled steel scrap and to a lesser extent, DRI. EAF-based processes are economic at smaller scales than integrated processes using basic oxygen furnaces, and are thus less capital-intensive. They are also less energy-intensive (if the energy embodied in scrap is not included). All minimills use EAFs, and some integrated producers augment their processes with EAFs. Until recently, minimills were limited in the set of products that they were capable of producing. Now, with control of residual elements and use of thin slab casting, minimills can produce nearly all the products available from integrated mills.

EAFs use 6.3 million Btu, on average, to in the produce of a ton of steel. State-of-the-art technologies such as scrap preheating, ultrahigh power (UHP) transformers, bottom tap furnaces, and water-cooled furnace panels and tops can reduce energy use by 20 percent from current average practices. The scrap would be preheated with waste heat from the furnace. UHP transformers would give furnaces shorter cycle times and correspondingly better productivity, thus reducing energy use because of the shorter period at high temperature.[85]

Secondary refining processes such as ladle refining are important auxiliaries to steelmaking furnaces. By carrying out part of the refining in vessels other than the furnace, these processes increase the productivity of the furnace and shorten the period each ton of steel spends at the very high temperatures.

Efforts are underway to develop an advanced direct steelmaking process. Direct steelmaking would replace the coke oven and blast furnace steps with one continuous process. Another advantage is that direct steelmaking can either use iron ore or scrap. The key to the success of this process is effectively transferring heat from postcombustion to the bath. The Oak Ridge National Laboratory (ORNL) estimates that direct steelmaking can reduce energy use by 20 to 30 percent and achieve production rates that are two to three times higher than those of a blast furnace.86

Another advanced technology that is under development is the ore-to-powder steelmaking process, which eliminates the ore melting process with magnetic separation and chemical leaching. ORNL estimates that this method may reduce energy use by 40 percent and also decrease capital costs. The need for highly-refined magnetic separation may be a technical barrier to using this method.[87]

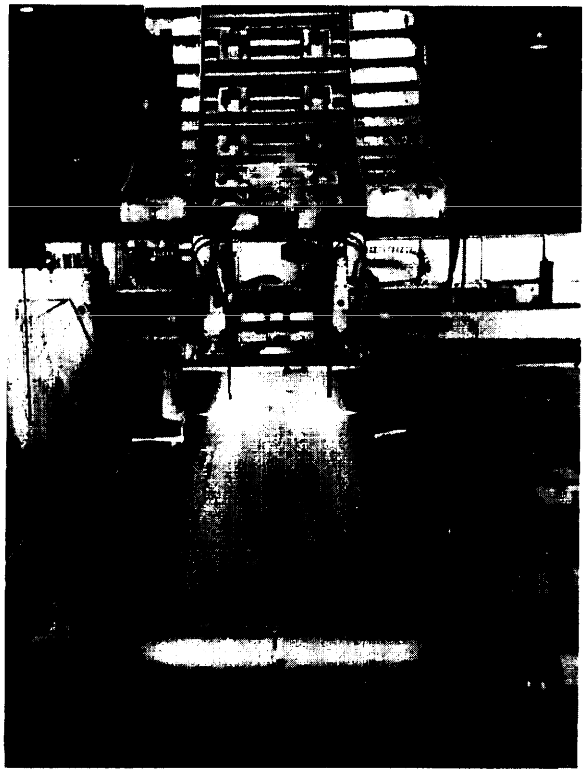
After the steelmaking step, the ore-based and scrap-based production routes converge, so this is an appropriate juncture to compare the energy intensities of these two basic production methods. Up through the steelmaking stage, the ore-coke-blast furnace-BOF route uses on average 15.9 million Btu/ton of raw steel. The scrap-EAF route uses on average 6.3 million Btu/ton, 60 percent less than the ore-based method. About 60 percent of U.S. steel is produced in BOFs and 36 percent is produced in EAFs (1989), resulting in an average of 12.4 million Btu of energy for each ton of raw steel produced (up through the steelmaking stage). State-of-the-art technologies are estimated to be capable of using 10.5 million Btu/ton of raw

---

[85] Sven Eketorpe, ‘‘Electrotechnologies and Steelma.king,” Thomas B. Johansson, Birgit Bodlund, and Robert H. Williams (eds.), *Electricity: Efficient End-Use and New Generation Technologies and Their Planning Implications* (Lund, Sweden: Lund University Press, 1989), pp. 261-296.

[86] Oak Ridge National Laboratory, Energy *Technology R&D: What Could Make a Difference?* op. cit., footnote 40.

[87] Ibid.



A slab being torch cut after emerging from a continuous slab caster.

AMERICAN IRON AND STEEL INSTITUTE

steel in the ore-coke-blast furnace-BOF route and 5.0 million Btu/ton of raw steel in the scrap-EAF route. The estimate for an advanced direct steelmaking process is 9.9 million Btu/ton. Direct steelmaking may hold many cost and environmental advantages, but the energy consumption advantages (compared with state-of-the-art conventional steelmaking processes) are not large.

PRIMARY FINISHING

Primary finishing includes the casting and initial rolling of steel into slabs (for flat sheets) and blooms and billets (for structural shapes and bars). Ingot casting involves pouring the liquid steel into molds to form ingots, which are later stripped, reheated, and rolled. Continuous casting pours the liquid steel directly into its semifinished shape.

Continuous casting eliminates the need for the stripper, reheating (soaking pit), and primary rolling mill associated with ingot casting. Continuous casting reduces energy use by about 50 percent, as compared with ingot casting. Also, continuous casting has a greater yield (95 percent) than ingot casting (82 percent), so less scrap metal must be returned to the steelmaking process in the form of waste and unfilled ingot molds. In addition, the product is often higher quality, and there are reduced emissions problems.[88] Because of these advantages, continuous casting has rapidly come to dominate the steel industry. In 1980, 20 percent of steel was continuously cast, and in 1989, 65 percent was cast this way.

A major breakthough in continuous casting, called thin slab casting, has been recently commercialized at the NUCOR, Inc. plant in Crawfordsville, Indiana.89 This innovative process has the potential to reduce energy use and production time considerably. For example, producing one-tenth of an inch thick slabs can be done in only 3 hours with a thin slab caster, but may take as long as a week with conventional procedures. Thin slab casting is enabling minimills to compete with integrated mills for the first time in the high-value sheet and strip product lines. The process could be used in integrated mills and minimills throughout the industry.

There are other advanced casting technologies (at various stages of development) that offer even greater potential capital and energy savings, and productivity improvements. These include: thin strip casting, net shape casting, and spray steel.

Primary finishing uses on average about 1.6 million Btu/ton of finished steel cast. State-of-the-

---

[88] Sayed A. Azimi and Howard E. Lowitt, Energetic, Inc., *The U.S. Steel Industry: An Energy Perspective,* prepared for the U.S. Department of Energy, Office of Industrial Programs, Report No. DOE/RL/01830-T55 (Springfield, VA: National Technical Information Service, January 1988).

[89] Jonathan p. Hicks, "Making Steel Faster and Cheaper, *The New York Times,* Business Technology, Feb. 27, 1991, pp. D-6 and 7.

art modern casters with slab heat recovery can reduce the energy use of this stage by an estimated 80 percent from current average practices.

FORMING AND HEAT TREATING

Forming, or secondary finishing, operations transform the steel slabs, blooms, and billets into their final shapes. Depending on the product, the process may involve, reheating, hot rolling, pickling, annealing, and cold rolling. Many of the forming operations are very electricity-intensive. Hot rolling, cold reduction, and finishing operations each consume about 125 kWh/ton. Hot rolling thin cast strip to cold-rolled gages in an inert atmosphere could eliminate a series of scale removal, cleaning, and annealing steps and ultimately save 50 to 100 kWh/ton.[90] State-of-the-art technologies include direct rolling of sheet and strip, which eliminates need for reheat furnace, reheat furnace waste heat recovery, and continuous cold rolling.

After forming, the steel is reheated and then allowed to cool slowIy in order to relieve the stresses built up within the steel by the rolling processes, This improves the strength and ductility of the final product. Heat treatment has experienced considerable efficiency gains in recent years. In the United States, energy consumption of heating and annealing furnaces dropped by nearly one-third between 1980 and 1989.[91]

Aluminum[92]

Aluminum is the second most widely used metal after steel. Its light weight, corrosion resistance, ease of recycling, and high electrical and thermal conductivity make it useful in a variety of applications in the container, packaging, transportation, building, and construction markets.

Aluminum can be recovered from many minerals (e.g., clays, anorthosite, nepheline syenite, and alunite), but is produced most economically from bauxite, an impure form of alumina (Al_2O_3). To extract the aluminum, the bauxite ore is refined into alumina and then smelted into aluminum.

Electric power accounts for about 26 percent of the aluminum industry's production costs, other energy sources account for an additional 1 percent (based on 1990 data).[93] As a consequence, aluminum production capacity is located in areas of abundant, inexpensive electricity. In the United States, smelter capacity is located roughly one-third in the Pacific Northwest, one-third in the Ohio Valley, and the rest in the Carolinas, New York, and Texas. Because of rising electricity prices, very little aluminum smelting capacity has been built in the United States in the recent past and none is expected to be built in the future.[94] Most new capacity, is being located in Australia, Canada, Brazil, and Venezuela.

ALUMINA REFINING: BAYER PROCESS

The Bayer refining process produces pure alumina from bauxite. The bauxite is crushed and ground, then digested in hot (280 to 450F) caustic soda (NaOH) solution. The alumina minerals in the ore react with the caustic soda and dissolve as sodium-aluminate. Most of the impu-

---

[90] Electric power Research Institute, *power Utilization in Flat Processing of* Steel, Report No. *EM-5996* (Palo Alto, CA: Electric Power Research Institute, January 1989).

[91] Energetics, Inc., *Industry Profiles: Steel,* op. cit., footnote 75.

[92] U.S. Congress, office of Technology Assessment, *Nonferrous Metals: Industry Structure,* OTA-BP-E-62 (Washington, DC: U.S. Government Printing Office, September 1990), ''Aluminum,'' *McGraw-Hill Encyclopedia on Science and Technology (New* York, NY: McGraw-Hill, 1987). Energetic, Inc., Industry *Profiles: Aluminum,* prepared for the U.S. Department of Energy, Office of Industrial Technologies, Report No. DE-AC01-87CE40762, December 1990.

[93] U.S. Department of Commerce, Bureau of the Census, 1990 *Annual Survey of Manufactures: Statistics for Industry* Groups *and Industries,* op. cit., footnote *24.*

[94] During *the 1980s, 10* aluminum smelters closed and capacity declined by 16 percent. The last new smelter in the United States opened in 1980.

Table 3-12—Energy Use by Aluminum Production Technologies

Process	Energy use (million Btu/ton of aluminum)		
	Current (1980)	State-of-the-art (2010)	Advanced (2010)
Alumina refining: Bayer process	*35.5*	*27.0*	*27.0*
Aluminum smelting: Hall-Heroult process			
Electrolysis (kWh per lb of aluminum)	***49.5 (7.3)***	***42.3 (6.2)***	
Fume recycling and other electricity	3.4 (0.5)	2.7 (0.4)	
Anode production: heat and energy	5.4	3.3	
Anode production: raw materials	14.6	12,5	
Fluoride production	2.0	0.4	
Subtotal	74.9	61.2	49.0[b]
Holding, casting, melting, alloying, and scrap remelting	*9.5*	*9.5*	*9.5*
Total ***end use energy***			
Based on domestic alumina refining	**119.8**	**97.7**	**85.4**
Based on imported alumina	**84.3**	**70.7**	**58.4**
Electricity losses [c]	*75.6*	*64.2*	*51.7*
Total ~	*177.7*	*148.4*	*123.6*

[a] Average of currently implemented technologies.

[b] Based on estimated 20 percent improvement in smelting energy efficiency.

[c] Assumes that 65 percent of electricity is produced from thermal sources (68 percent losses) and 35 percent is produced from hydro sources (10 percent losses).

[d] Assumes that half of the alumina is refined domestically and half is imported.

NOTE: Purchased electricity is counted at 10,500 Btu/kWh; generation and transmission losses are included.

SOURCES: S.Y. Shen, Argonne National Laboratory, *Energy and Materials Flows in the Production of Primary Aluminum,* Report No. ANL/CNSV-21 (Springfield, VA: National Technical Information Service, October 1981). R.M. Arons and A.M. Wolsky, Argonne National Laboratory, *Energy and Materials Flows in the fabrication of Aluminum Products,* Report No. ANL/CNSV-3 (Springfield, VA: National Technical Information Service, August 1978). Energetic Inc., *industry Profiles: Aluminum,* prepared for the U.S. Department of Energy, Office of Industrial Technologies, Report No. DE-AC01-87CE40762, December 1990.

rities in the ore precipitate out as ‘‘red mud, ’ which is removed by countercurrent recantation and filtration. The solution is then seeded with starter crystals and agitated to crystallize out alumina hydrate. This material is then calcined in kilns (to remove the water) and the result is pure alumina.

Alumina refining accounts on average for about 27 percent of the energy used in aluminum production (based on 1980 data). State-of-the-art technologies can reduce energy use in alumina production by 24 percent (tables 3-12 and 3-13). However, these savings do not apply to all aluminum production, because about half of U.S. alumina supplies are imported instead of refined domestically.

ALUMINUM SMELTING: HALL-HEROULT PROCESS

The Hall-Heroult smelting process reduces the alumina to aluminum. Alumina is dissolved in a molten cryolite (Na_3AlF_6) bath contained in carbon-Lined steel cells (pots). In each pot, a direct current is passed through the bath (between a carbon anode and the carbon bottom of the cell) to reduce the dissolved alumina into aluminum. Molten aluminum collects at the bottom of the pots and is siphoned off into large crucibles. The aluminum (averaging about 99.8 percent purity) is poured directly into molds to produce foundry ingot or further refined and/or alloyed to make fabricating ingot. Scrap aluminum may be added to the melt either at this last stage or when the ingot is remelted at the foundry or fabricating

Table 3-1 3—Major Energy Saving Features of Improved Aluminum Production

Process	State-of-the-art	Advanced
Aluminum smelting (Hall-Heroult process)		
Electrolysis	More efficient rectifiers and computer control of amperage flow. Design changes in carbon anodes. Improvements in the chemical bath. Low-current density design cells. Increased furnace insulation.	*Retrofit* Closer anode-cathode spacing. Highly conductive electrolyte. Bipolar anode-cathode assemblies. Soderberg conversion. *Replacement* Pora composite anode. Advanced technology reduction cell, with bipolar electrode with 3, 4, and 5 bipolar plates. Alcoa aluminum chloride smelting process. Inert anode. Carbothermic reduction process. Advanced technology reduction cell. MonoPolar electrode.
Anode production		*Retrofit* Composite anodes. Oxygen resistant, high electrical conductivity material for anodes. Solvent refined coal or lignite liquids. *Replacement* Inert anode, cathode, and sidewalls. Carbothermic reduction process.

SOURCE: Energetic, Inc., *Industry Profiles: Aluminum,* prepared for the U.S. Department of Energy, Office of Industrial Technologies, Report No. DE-AC01-87CE40762, December 1990.

facility. The carbon anodes, which are consumed in the process, are produced at the smelter by baking petroleum coke and coal tar pitch at 1,800 F .

The smelting process is continuous. Alumina is added, anodes are replaced, and molten aluminum is siphoned off without interrupting current in the cells. A potline may consist of 50 to 200 cells with a total line voltage of up to 1,000 volts at current loads of 50,000 to 225,000 amps.

Smelting accounts on average for 65 percent of the energy used in aluminum production (based on 1980 data). Most of this energy is electricity. Electricity use in the electrolysis section of smelters currently averages about 7.3 kWh/lb of aluminum.[95] Modern, state-of-the-art smelters use 6.0 to 6.5 kWh/lb.

Energy use in the Hall-Heroult process is determined by the design and operation of the electrolysis cell. About 45 percent power of the energy input is used to reduce the alumina to aluminum, and the remainder is lost as heat. The primary cause of this low efficiency is the spacing (typically 1.75 inches) between the anodes and cathodes. Narrower electrode spacings give lower power consumption and improved energy efficiency. However, there are limits to how close the electrodes can be spaced. Undulation in the metal

---

[95] Though the basic process Of aluminum smelting is over 100-years-old, the technology has improved steadily. Just after World War II, about 12 kWh of electricity was required to produce a pound of aluminum.

bath (caused by magnetic fields interacting with metal pad currents and gases from the deteriorating anodes) can periodically short out the circuit if the electrodes are spaced too closely. It is estimated that reducing anode-cathode spacing from 1.75 to .75 inches could reduce electrolysis electricity use by 23 percent, and that reducing the spacing to .25 inches would result in energy savings of 33 percent. Realizing these potential savings would require developments in cell design, electrode and lining materials, and electrolyte composition.[96]

RECYCLING

Scrap recycling reduces significantly the energy used to produce aluminum products. Recycling requires only about 5 percent of the energy needed to produce primary aluminum from bauxite. In recent years, recycling has accounted for about one-third of total aluminum production in the United States.[97]

SUMMARY

Most improvements in aluminum production are expected to be marginal over the next 20 years. Full implementation of state-of-the-art technologies, such as more efficient rectifiers and computer control of amperage flow, would lower energy use by an estimated 16 percent from current average practices.[98] If breakthroughs were made in the development of advanced technologies, such as the Pora composite anode, the inert anode, or carbothermic reduction process, energy use may be reduced by an additional 17 percent.

1 Cement[99]

Cement is the bonding agent that holds particles of aggregate together to form concrete. Cement production is very energy-intensive, but the final concrete is one of the least energy-intensive construction materials.

The raw materials for Portland cement, the most commonly used cement, are limestone (calcium carbonate), silica sand, alumina, iron ore, and small quantities of other materials. These materials are quarried, crushed, ground, and mixed together, and then burned at 2,700 to 2,900°F in large rotary kilns. This sinters and partially fuses the materials into marble-sized pellets known as clinker. The clinker is then cooled, ground into a fine powder, and mixed with gypsum for use as cement. The main processes involved in cement manufacture are raw materials preparation, clinker production, and finish grinding.

There are two principal categories of cement production, the wet process and the dry process. In the wet process, water is added to the process stream at the grinding stage and later the materials are fed into the kiln as a slurry. In the dry process, the raw materials are ground without water, then preheated or precalcined, and finally fed into the kiln as a dry meal that contains less than 7 percent moisture. The preheat and precalcine stage uses waste heat from the kiln. In some plants, this intermediate stage is skipped and the dry ground materials are fed directly into the kiln.

The choice of whether to process wet or dry depends on the initial moisture content of the raw materials. Materials with greater than 15 percent

---

[96] Energetic, Inc., *Industry Profiles: Aluminum*, op. cit., footnote 92.

[97] Patricia A. Plunkert and Errol D. Sehnke, "Aluminum, Bauxite, and Alumina," *Minerals Yearbook, vol. I*, 1990 ed. (Washington, DC: U.S. Department of the Interior, Bureau of Mines, 1993).

[98] This assumes that one-half of the U.S. alumina supply continues to be imported.

[99] "Cement," The *Academic American Encyclopedia, online edition* (Danbury, CT: Grolier Electronic Publishing, 1991). U.S. Congress, Office of Technology Assessment, *Fueling Development: Energy Technologies for Developing Countries*, op. cit., footnote 12. Energetic, Inc., *Industry Profiles: Cement*, prepared for the U.S. Department of Energy, Office of Industrial Technologies, Report No. DE-AC01-87CE40762, December 1990.

moisture are wet processed, because there is insufficient waste heat from the kiln to reduce their moisture content to levels low enough for dry processing. The dry process is the most popular of the two production methods and its use has been growing because of its greater energy efficiency.

The energy sources of the wet and dry processes differ considerably, with the dry process using somewhat more electrical energy and substantially less thermal energy. In recent years, electricity use in cement manufacture has increased because of the shift to the dry process, greater environmental controls, and more extensive use of preheater that require large fan systems. In addition, greater production of more finely ground, higher strength cements has also increased electricity use.[100] This is partially offset because less cement is needed when higher strength types are used.

RAW MATERIALS PREPARATION

This step, which includes the crushing, proportioning, drying, grinding, and blending of the various minerals, accounts for about 8 percent of the energy used in cement manufacturing (tables 3-14 and 3-15). The grinding stage, which consumes the most energy, is done either wet or dry. The wet process requires less energy at the grinding stage, but much more energy in clinker production. Grinding is particularly inefficient, with an estimated 2 to 5 percent of the input energy going to breaking materials apart, and the remainder going into heat and vibration. Full use of state-of-the-art technologies such as the dry process, with additional drying in the mills and improved classification schemes, are estimated to reduce energy use in raw materials preparation by about 19 percent from current average practices. Technologies, not yet commercialized, such as advanced sensors and instrumentation, modeling and controls for grinding circuits, and differential grinding, may be able to reduce the energy use an additional 23 percent.

CLINKER PRODUCTION

Sintering and fusing the ground materials into clinker is the most energy-intensive stage of the process. It accounts for approximately 80 percent of the energy used in cement production. The dry process with precalcining or preheating uses the least energy, the wet process uses the most. Advances in the preheater and precalciner processes have led to significant improvements in the overall energy efficiency of cement production in recent years.

State-of-the-art technologies, such as the dry process with either preheat or precalcine and improvements in kiln refractories, kiln combustion, and improved clinker cooling techniques, are estimated to reduce energy use in clinker production by about 26 percent from current average practices. Advanced technologies such as catalysts to lower calcination temperatures, advanced kiln control based on artificial intelligence, and modifications to alkali specifications may be able to reduce the energy use an additional 17 percent.

FINISH GRINDING

Grinding the clinker into a fine powder and mixing it with gypsum accounts for about 11 percent of the energy use of cement production. The same low (2 to 5 percent) grinding efficiencies that exist in the raw materials stage exist here

---

[100] Stewart W. Tresouthick and Alex Mishulovich, "Energy and Environment Considerations for the Cement Industry, " paper presented at the Energy and the Environment in the 21st Century conference. Massachusetts Institute of Technology, Cambridge, MA, Mar. 26-28, 1990.

Table 3-14—Energy Use by Cement Production Technologies

	Process mix (fraction of clinker processed, except where noted)			Energy use (thousand Btu/ton of clinker)		
	Current	State-of-the-art	Advanced	Current	State-of-the-art	Advanced
Process	(1988)	(2010)	(2010)	(1988)	(2010)	(2010)
Raw materials preparation						
Primary crushing	1.00	1.00	1.00	26	24	42
Secondary crushing	1.00	1.00	—	32	28	[b]
Proportioning	1.00	1.00	1.00	21	19	19
Drying	0.16	—	—	270	—	—
Raw grinding (wet)	0.34	—	—	275	—	—
Raw grinding (dry)	0.66	1.00	1.00	312	270	203
Blending	1.00	1.00	1.00	2	2	2
Subtotal				425	343	266
Clinker production						
Long kiln (wet)	0.34	—	—	4,932	—	—
Long kiln (dry), no preheat/precalcine	0.16	—	—	4,294	—	—
Short kiln (dry), with preheat	0.20	0.20	—	3,469	3,000	—
Short kiln (dry), with precalcine	0.30	0.80	0.80	3,332	3,000	2,500
Stationary clinkering, with precalcine	—	—	0.20	—	—	2,360
Clinker cooling	1.00	1.00	1.00	63	57	57
Subtotal				4,121	3,057	2,529
Finish grinding						
Ball milling	0.95	—	—	525	—	—
Ball milling, with pregrinding	0.05	0.99	0.70	473	378	321
Roller milling	—	0.01	0.20	—	420	315
Nonmechanical grinding	—	—	0.10	—	—	300
SubtotaL				522	378	318
Total						
From domestic clinker	97%	93%	7470	5,067	3,778	3,112
From imported clinker	30/0	7%	6%	522	378	318
From secondary materials	—	—	20%	—	—	—
Weighted average				4,925	3,528	2,325

[a] Average of currently implemented technologies.

[b] Included in primary crushing.

NOTE: Purchased electricity is counted at 10,500 Btu per kWh; generation and transmission losses are included. Estimated losses in 1988 were approximately 944 thousand Btu per ton of cement.

SOURCES: S.R. Venkateswaren and Howard E. Lowitt, Energetic, Inc., *The U.S. Cement Industry: An Energy Perspective,* prepared for the U.S. Department of Energy, Office of Industrial Programs, Report No. DOE/RL/01830-T58 (Springfield, VA: National Technical Information Service, May 1988). Energetic Inc., *Industry Profiles: Cement,* prepared for the U.S. Department of Energy, Office of Industrial Technologies, Report No. DE-AC01-87CE40762, December 1990.

as well. Addition of a pregrinding stage saves about 10 percent of the energy used in grinding. Currently, only about 5 percent of clinker is preground.

State-of-the-art technologies, such as pregrinding and improvements in the grinding media and classification techniques, are estimated to reduce energy use in finish grinding by about 28 percent from current average practices. Partial use of advanced technologies such as roller milling and nonmechanical comminution might be able to reduce energy use an additional 16 percent.

Table 3-15—Major Energy Saving Features of Improved Cement Production

Process	State-of-the-art	Advanced
Raw material preparation	Wet process slurry dewatering with filter presses and slurry thinners. Waste heat drying using preheater exit gases/cooler heat in roller or air-swept ball mills. High-efficiency classifiers in closed-circuit grinding plants. Roller mills. Improved grinding media and wear resistant linings.	Fluidized-bed drying with low-grade fuels. Advanced sensors for particle size, fineness, and mass flow measurements and automatic computer control of grinding circuits. Differential grinding: limestone and clay raw materials ground separately. Nonmechanical comminution, based on ultrasound, lasers, thermal shock, electrical shock, or cryogenics.
Clinker production	Dry precalciner kilns. Dry suspension preheater kilns. Use of waste fuels, including: coke, municipal wastes, rice hulls, wood wastes, rubber tires, hazardous wastes, waste oil, pot liners, sewage sludge, etc. Optimized heat transfer conditions in the clinker cooler through better distribution of clinker and air. Improved insulating refractories and seals to reduce kiln shell heat loss. Kiln combustionimprovements, including semi-direct/indirect coal firing, optimal oxygen levels, and advanced burners matched to the kiln/coler design. Material recirculation in flash precalciners to improve calcination efficiency. Cogeneration using exhaust heat from kiln and/or coler. Kiln internal heat transfer enhancement: chains, lifters, and trefoils. Low pressure-drop cyclones for suspension preheater. High-temperature ceramic filters for kiln exhaust.	All electric kilns and hybrid fossil-electric kilns. Stationary clinkering systems, including fluidized-bed kilns and trough kilns. Sensors and online analysis of kiln exhaust, temperature and clinker quality, and high level computer-based kiln control. Alkali specification modification.
Finish grinding	Roller mills. High-efficiency classifiers in closed circuit plants. High-pressure roller press for clinker pre-grinding. Improved grinding media and wear resistant linings. Modified bail mill configuration and operation. Particle size distribution control. Grinding aids.	Blended cements: Portland cements with fly ash, kiln dust, blast furnace slag, and natural pozzolana. High-pressure roller press as an autonomous grinding unit. Modified fineness specification. Advanced sensors for particle size, fineness, and mass flow measurements and automatic computer control of grinding circuits. Nonmechanical comminution, based on ultrasound, lasers, thermal shock, electrical shock, or cryogenics.

SOURCE: S.R. Venkateswaren and Howard E. Lowitt, Energetic, Inc., *The U.S. Cement Industry: An Energy Perspective,* prepared for the U.S. Department of Energy, Office of Industrial Programs, Report No.DO13RI_101830-T58 (Springfield, VA: National Technical Information Service, May 1988). Energetic, Inc., *Industry* Profiles: *Cement,* prepared for the U.S. Department of Energy, Office of Industrial Technologies, Report No. DE-AC01-87CE40762, December 1990.

Glass[101]

Glass is produced by melting silica, limestone, and soda ash, in a furnace and allowing them to cool to an amorphous (noncrystalline) state.[102] Other elements may be added to alter the color or other properties. While still molten, the glass is formed into a variety of products including: windows, mirrors, bottles, jars, light bulbs, tableware, and fiberglass. The principal processing steps are batch preparation, melting and refining, forming, and postforming.

The energy used to manufacture glass varies significantly among the major categories of glass products: flat, containers, pressed and blown, and fibrous. Currently, between 15 and 27 million Btu are used on average to produce a ton of glass, depending on the product (based on 1985 data). For the industry as a whole, widespread adoption of state-of-the-art technologies can reduce energy consumption by an estimated 21 percent (tables 3-16 and 3-17) from current average practices. The estimated reductions are greatest for flat glass and smallest for fibrous glass. Advanced technologies, not yet commercialized, could possibly reduce energy use an additional 30 percent.

BATCH PREPARATION

Glassmaking begins with raw materials weighing and mixing. Recycled material (cullet) is crushed and added to the process at this stage. Batch preparation accounts for an average of 4 percent of the energy used in glass production. Computer control for the weighing, mixing, and charging saves about 10 percent of the energy used in batch preparation.

MELTING AND REFINING

The raw materials are batch charged or continuously charged to the melting furnace, where they are heated to between 2,400 to 2,900°F. After melting, the glass passes to the refining section of the furnace where it stays long enough for the bubbles to escape. Glass is produced in various types of melters including regenerative, recuperative, electric, and pot furnace or day furnaces. Most furnaces are freed by gas or oil, but electricity is becoming more widely used.

Regenerative furnaces are used in large continuous melting operations and account for approximately 90 percent of U.S. capacity. The charge is melted by a flame that plays over the glass surface. Fuel and preheated air are fired at one end of the furnace and the hot combustion exhaust gases pass through an open brick lattice (checker) at the opposite end. After 15 minutes, the flow is reversed. The air is preheated by passing through the hot checker and the exhaust gases from the combustion heat the checker at the other end for the next cycle. Recuperative furnaces are similar, except that they were originally built without checkers and have since been retrofitted with heat recovery units. Fossil-fueled, regenerative furnaces are 40 to 55 percent efficient in terms of end-use energy.

Electric melters heat the glass by passing current between electrodes embedded in the charge. These melters are approximately 60 to 75 percent efficient in terms of end-use energy. Among the advantages of electric melting are: reduced pollution; improved glass quality (more uniformity and fewer stones); better control of operations; faster furnace rebuilds; and small

---

[101] "Glass and Glass Products," ***McGraw-Hill** Encyclopedia on Science and Technology (New* York, NY: McGraw-Hill, 1987). "Glass," *The Academic American Encyclopedia, online edition* (Danbury, CT: Grolier Electronic Publishing, 1991). E. Babcock, A. Elaahi, and H.J.?. Lowitt, Energetic, Inc., *The U.S. Glass Industry: An Energy Perspective,* prepared for the U.S. Department of Energy, Office of Industrial Programs, Report No. DOE/RL/O1830-T60 (Springfield, VA: National Technical Information Service, September 1988).

[102] Glass can be produced without silica, but most commercial glass products are based on it.

Table 3-16—Energy Use by Glass Production Technologies

Process	Process mix (tons of product/ton of finished glass) Current (1985)	State-of-the-art (2010)	Advanced (2010)	Energy use (million Btu/ton of product) Current* (1985)	State-of-the-art (2010)	Advanced (2010)	Product
	32	.32	26	0.27	0.24	0.24	Batch processed glass
Melting and refining							
Large fossil fuel melter	.26	.26	—	8.10	5.10	—	Melted glass
Advanced melter with batch preheat	—	—	1.20			3.00	Melted glass
Subtotal	.26	.26	1.20	8.10	5.10	3.00	Melted glass
Forming	.26	.26		.45	1.30	.17	Formed glass
Post-forming							
Annealing	1.20	1.20	—	0.42	0.27	—	Postformed glass
Tempering	0.60	0.60	—	3.03	2.14	—	Postformed glass
Laminating/autoclaving	0.40	0.40	—	0.82	0.75	—	Postformed glass
Advanced	—	—	1.20	—	—	1.36	Postformed glass
Subtotal	1.20	1.20	1.20	2.20	.59	1.36	Postformed glass
Total	1.00	°0	.00	15.03	10.28	6.93	Finished glass
Container glass							
Batch preparation	1.32	.32	.24	0.53	0.48	0.48	Batch processed glass
Melting and refining							
Large fossil fuel melter	1.01	1.0		5.50	3.90	—	Melted glass
Small fossil fuel melter	0.19	0.19	—	9.42	8.35	—	Melted glass
Small electric melter	0.06	0.06	—	10.50	8.90	—	Melted glass
Advanced melter with batch preheat	—	—	1.19	—	—	3.00	Melted glass
Subtotal	1.26	1.26	1.19	6.34	4.82	3.00	Melted glass
Forming	1.20	.20	1.13	4.0	3.20	2.88	Formed glass
Post-forming							
Annealing	1.13	1.13	—	1.84	1.40	—	Postformed glass
Advanced	—	—	1.13	—	—	1.33	Postformed glass
Subtotal	1.13	1.13	1.13	.84	1.40	1.33	
Total	1.00	1.00	1.00	15.59	2.14	8.9	Finished glass

Table 3-16-Energy Use by Glass Production Technologies-(Continued)

Process	Process mix (tons of production of finished glass)			Energy use (million Btu/ton of product)			Product
	Current (1985)	State-of-the-art (2010)	Advanced (2010)	Current[a] (1985)	State-of-the-art (2010)	Advanced (2010)	
Pressed and blown glass							
Batch preparation	1.51	1.51	1.51	0.76	0.68	0.68	Batch processed glass
Melting and refining							
Small fossil fueled melter	1.30	1.30	—	10.10	8.00	—	Melted glass
Small electric melter	0.14	0.14	—	9.90	8.90	—	Melted glass
Advanced melter with batch preheat	—	—	1.30	—	—	3.00	Melted glass
Moly-lined electric melter	—	—	0.14	—	—	6.70	Melted glass
Subtotal	1.44	1.44	1,44	10.08	8.09	3.37	Melted glass
Forming	1.37	1.37	1.37	5.31	4.50	4.05	Formed glass
Post-forming							
Fire polishing	1.37	1.37	—	1.20	1.10	—	Postformed glass
Annealing	1.37	1.37	—	2.04	1.79	—	Postformed glass
Advanced	—	—	1.37	—	—	2.74	Postformed glass
Subtotal	1.37	1.37	1.37	3.24	2.89	2.74	Postformed glass
Total	1.00	1.00	1.00	27.37	22.80	15.18	Finished glass
Fibrous glass							
Batch preparation	1.30	1.30	1.30	1.15	1.04	1.04	Batch processed glass
Melting and refining							
Small fossil-fueled melter	1.11	1.11	—	9.89	9.08	—	Melted glass
Small electric melter	0.12	0.12	—	9.90	8.90	—	Melted glass
Advanced melter with batch preheat	—	—	1.11	—	—	3.00	Melted glass
Moly-lined electric melter	—	—	0.12	—	—	6.70	Melted glass
Subtotal	1.24	1.24	1.24	9.89	9.06	3.37	Melted glass
Forming	1.11	1.11	1.11	7.24	6.00	5.40	Formed glass
Post-forming							
Curing	1.00	1.00	—	1.10	0.94	—	Postformed glass
Drying	1.00	1.00	—	1.64	1.40	—	Postformed glass
Advanced	—	—	1.11	—	—	2.22	Postformed glass
Subtotal	1.00	1.00	1.11	2.74	2.34	2.22	Postformed glass
Total	1.00	1.00	1.00	24.51	21.56	13.98	Finished glass

[a] Average of currently implemented technologies.

NOTE: Purchased electricity is counted at 10,500 Btu/kWh; generation and transmission losses are included. Estimated losses in 1985 *were* approximately 2.6 million Btu/ton of flat glass; 4.4 million Btu/ton of container glass; 9.2 million Btu/ton of pressed and blown glass; and 7.6 million Btu/ton of fibrous glass.

SOURCES: E. Babcock, E. Elaahi, and Howard E. Lowitt, Energetic, Inc., *The U.S. Glass Industry: An Energy Perspective,* prepared for the U.S. Department of Energy, Office of Industrial Programs, Report No. DOE/RL/01830-T60 (Springfield, VA: National Technical Information Service, September 1988). Energetic Inc., *Industry Profiles:* Glass, prepared for the U.S. Department of Energy, Office of Industrial Technologies, Report No. DE-AC01-87CE40762, December 1990.

Tables 3-17—Major Energy Saving Features of Improved Glass Production

Process	State-of-the-art	Advanced
Batch preparation	Computer controlled weighing and mixing and charging.	Batch preheating. Cullet preheating. Raw material purification.
Melting and refining		
Gas/oil-fired melters	Oxygen-enriched combustion air. Electric boosting. Dual-depth melter. Regenerator flow controller (process control). Chimney block regenerator refractories. Chemical boosting. Oxygen monitoring (process control). Sealed-in burner systems. Reduction of regenerator air leakage.	Submerged burner combustion. Batch liquefaction. Advanced glass melter. Thermochemical recuperator. Ultrasonic agitation and refining. Pressure swing absorption oxygen generator. Excess heat extraction from generators. Improved furnace insulation.
Electric melters	Automatic tap changing transformers for electric melters. Dual-depth melter.	Molybdenum lined electric melter.
Coal-fired melters		Direct coal firing (substitution of coal for gas or oil). Coal-fired hot gas generation (COHOGG)(substitution of coal for gas or oil).
Chemical process		Sol-gel process.
Forming	Computerized inspection.	Improved productivity, resulting from greater production of lighter weight containers and tempered flat glass products. Improved mold design. Improved mold cooling systems. Automatic gob control.
Post-forming	Computerized inspection.	Improved productivity, resulting from greater production of lighter weight containers and tempered flat glass products. Improved glass strengthening techniques. Improved protective coating for glass.

SOURCES: E, Babcock, A. Elaashi and Howard E. Lowitt, Energetic, Inc., *The U.S. Glass Industry:An Energy Perspective,* prepared for the U.S. Department of Energy, Office of Industrial Programs, Report No, DOE/RL/01830-T60 (Springfield, VA: National Technical Information Service, September 1988). Energetic, Inc., *Industry Profiles: Glass,* prepared for the U.S. Department of Energy, Office of Industrial Technologies, Report No. DE-ACO1-87CE40762, December 1990.

space requirements.[103] However, there are also major drawbacks, including: electricity costs, reduced refractory life, more frequent furnace rebuilds, capacity limitations, and the inability melt glasses that are oxidizing or that contain metals that attack the molybdenum electrodes.

Melting and refining account for 50 to 68 percent of the energy used in glass production and are the focus of energy conservation efforts in the industry. State-of-the-art technologies such as oxygen-enriched combustion air, electric boosting, improved process control, and better refracto-

---

[103] E. Babcock, A. Elaahi, and H.E. Lowitt, Energetic, Inc., op. cit., footnote 101.

ries can reduce the energy use of this stage by an estimated 8 to 37 percent from current average practices. Advanced technologies could possibly reduce energy use an additional 38 to 63 percent.

FORMING

Once refined, the molten glass flows to the forehearth section of the furnace where it is homogenized and heat conditioned to establish and maintain temperature uniformity. Overall, the melt is cooled to the proper working temperature, where its viscosity is suitable for shearing and gob formation. However, it must also be heated periodically to eliminate temperature gradients within the glass. The cooling function interferes with the heating function, making the forehearth a larger energy user.

Molten glass is drawn from the forehearth when it is ready to be formed. The forming stage differs greatly depending on the product being produced.

Flat products such as windows are formed primarily by the float glass process developed in the 1950s. In the float process, a continuous strip of glass from the melting furnace floats onto the surface of a molten metal, usually tin, at a carefully controlled temperature. The flat surface of the molten metal gives the glass a smooth, undistorted surface as it cools. After sufficient cooling the glass becomes rigid and can be handled on rollers without damaging the surface finish. The glass can be formed at high speeds and is much less expensive to produce than similar quality glass made by grinding and polishing methods.

Containers are formed by blowing or suction techniques. To form a jar or bottle, a gob of hot glass is blown or sucked into a mold on a continuous machine. Light bulbs are produced by a similar technique, except that the glass is fed into the forming machine as a ribbon, rather than individual gobs of glass, and a special nozzle blows glass from the ribbon into the molds. A high-speed ribbon machine produces light bulbs at a rate of more than one every 2 seconds.

Products such as tableware, cooking utensils, and laboratory equipment are produced by blowing and pressing techniques. A gob of hot glass is placed in a metallic mold, and a metallic plunger is forced into the mold to form the glass into the desired shape. Patterns in the mold surface are pressed onto the glass.

Fiberglass is formed by one of four techniques: rotary fiberization, steam or air blowing, mechanical drawing, and flame blowing. In the rotary process, glass is extruded from holes on the periphery of a spinning mold. After extrusion, the diameter of the fibers is reduced (attenuated) by a blast of hot air or gas. The other processes all extrude the glass through holes in a stationary platinum mold, but differ in their attenuation techniques.

Forming accounts for 12 to 33 percent of the energy used in glass production. State-of-the-art forehearth technologies can reduce the energy use of this stage by an estimated 10 to 20 percent from current average practices. Advanced technologies could possibly reduce energy use an additional 10 percent.

POSTFORMING

Postforming operations are used to adjust the strength and other properties of the formed product. Like the forming stage, these processes vary according to the product being made. Flat products are annealed and cut, and then either tempered and quenched or laminated and autoclaved. Sometimes they are also coated. Containers and pressed and blown products are annealed, coated, and finished. Pressed and blown products are sometimes cut and fire polished. Fiber glass is either dried or cured.

Postforming accounts for about 11 to 18 percent of the energy used in glass production, State-of-the-art technologies can save an estimated 11 to 28 percent of this energy from current average practices. Advanced technologies could possibly reduce energy use an additional 5 to 14 percent.

---

[103] E. Babcock, A. Elaahi, and H.E. Lowitt, Energetic, Inc., op. cit., footnote 101.

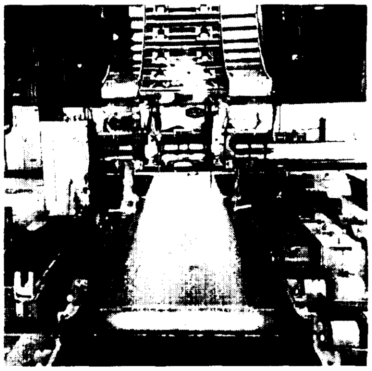
Energy in the Corporate Context

4

Corporations' internal cultures and external relationships are very important influences on industrial energy use and efficiency. The first part of this chapter discusses the internal climate and decisionmaking practices underlying investment in general, and investment in energy efficiency in particular. The second part focuses on relationships between corporations and their energy utilities and on utility efforts to improve industrial energy efficiency.

INVESTMENT IN EFFICIENCY

The improved equipment, processes, and practices described in the previous chapter enhance energy efficiency only to the extent that private companies use them in actual production settings. The investment and implementation step encompasses several major hurdles. Technical and economic feasibility are the most commonly studied of the factors influencing energy efficiency investment, but companies' general willingness to invest in process improvements, their energy awareness, and their access to information also have important impacts,



The Will to Invest

Perhaps the most important factor affecting industrial energy efficiency is the willingness of firms to invest in new technologies, whether energy-focused or not. Capital investment in modern equipment usually enhances energy efficiency, even when efficiency is not the primary purpose of the investment. The propensity to invest depends on the business climate, corporate culture, managers' personalities, and regulations. These determine the incentives for corporations in general and managers in particular to improve their production processes.

BUSINESS CLIMATE AND CORPORATE CULTURE

The working cultures of corporations emanate to a large extent from the dominant figures within those organizations. However, business climates also foster and shape corporate culture. For example, companies in young, high-growth industries tend to invest heavily in innovative products and technologies in order to build market share. In mature industries with price-based competition and low margins, companies, especially small ones, may have little incentive and few resources to invest.

A business climate imbued with strong market growth and competition is important for fostering investment. Without market growth, corporations have neither the resources nor the incentive to invest. Without competition, companies are under little pressure to invest. Competition that is vigorous, but fair, signals to companies that being profitable depends on being efficient with respect to energy as well as other production inputs. If profits are secure without investment, there will be no investment.

Competitive survival in the face of economic hard times or a vastly superior competitor can be a major impetus to aggressively improve energy costs and efficiency. For example, U.S. copper companies reduced their energy use significantly when they restructured themselves in the rnid-1980s to remain competitive in world markets.1

The effects of the business environment on corporate culture and managers' decisionmaking and investment behavior are illustrated in table 4-1.2 Within these categories are managers that invest readily, ones that would invest if capital were more available, and ones that are reluctant to invest in almost any circumstance. Decisions by hands-on managers occur quickly, while those by bureaucrats are long and involved.

MANAGERS' PERSONALITIES

Corporations are not monolithic, and neither are their investment strategies. Decisions about investments are made by many managers, acting either as individuals or groups. The managers respond to different stimuli and react to situations in different ways. No one type of incentive system works for all managers. Once their basic goals regarding production quotas, reject rates, and other factors have been met, managers differ in their effort and desire to improve production processes and products. In the context of the "if it's not broke, don't fix it adage, managers differ in their ideas about what is meant by ''broke. ' For some, an operation is ''broke' only if it is not up and running. They are satisfied if they are meeting their basic goals, and only "fro' things when those goals are not being met. For other managers, an operation is ''broke" if it can be improved. These managers continue ''fixing' things until the process is producing high-quality products as efficiently as possible.

REGULATIONS

Investment can also be mandated, as in the case of environmental regulation. In some cases, mandated investment can increase the efficiency and competitiveness of companies. In other cases, regulatory mandates can lead to higher costs and greater energy use, and in severe cases, lead to plant closures and capital migration. This can happen if the mandated costs are too onerous and if foreign competitors do not face commensurate increases in production costs or tariffs. Higher costs do not, however, automatically lead to plant closures. There are tradeoffs among the costs of doing business, the costs of relocating, and the benefits of being close to markets.

---

[1] U.S. Congress, Office of Technology Assessment, *Copper: Technology and Competitiveness, OTA-E-367* (Washington DC: U.S. Government Printing Office, September 1988).

[2] The categories, which were developed to describe managers in commercial firms, are also applicable to managers in small- and medium-sized industrial firms. Managers in large firms are more difficult to categorize, because their behavior is more strongly governed by corporate cultures that are unique to their firms.

Table 4-l-Categories of Managerial Behavior

Manager type	Industry type	Management characteristics
Enlightened managers	High growth.	Early adopters of technologies who closely monitor and control energy consumption and expense, and seek to maximize equipment efficiency and reliability.
Bureaucrats	Slow, but stable, growth.	Shortsighted, risk averse, and somewhat cash constrained. Multiple decisionmakers and lengthy, formal, decision cycle.
Survival-focused	On the edge of bankruptcy.	Focus exclusively on activities that will generate cash to keep the business afloat. Emphasis on revenue generation over cost reduction. Minimize financial risks.
Hands-on managers	Business built around a somewhat price-insensitive product.	A simple decisionmaking structure anchored by a single individual who is directly involved in the daily operations of the business. Focus on decreasing operating costs more than increasing revenue. Avoids financial risks and investments in new technologies regardless of the potential benefits.
Operating cost sensitive	Volatile growth.	Prevalent concern for managing and containing operating costs. Uses a rigorous set of financial criteria to guide acquisition decisions and performance.
Innovators	Slow, but steady growth.	Commitment to innovation in product line and business as a whole. Pays more attention to operating costs and efficiencies than to initial costs of energy-related equipment. Willing to adopt new energy management technologies and invest managerial time in monitoring and controlling energy costs.
Constrained relationship seekers	Highly energy intensive and highly leveraged.	Recognize opportunities to achieve greater efficiency, but high debt loads and lack of cash prevents the acquisition of fuel-efficient technologies and the expertise to manage energy consumption.
Uninvolved	Mature products in mature markets. Slow, but occasionally volatile, growth.	Averse to adopting new technologies in particular and risk in general. Negligible concern about energy.
Complacent	Perceived price insensitive markets.	Risk averse and unwilling to invest in new technologies, and are not particularly sensitive to cost control.

SOURCE: Electric Power Research Institute, *An Overview of EPRI's Commercial Needs-Based Market Segmentation Framework,* EPRI Project No. RP2671-01 (Palo Alto, CA: Electric Power Research Institute, November 1990).

Energy Awareness

If there is a willingness to invest, the next hurdle is for managers to know how energy is used in their plants and to be aware of technologies available to improve the situation. Industrial companies view energy primarily in terms of cost. They have direct financial incentives for reducing their energy costs by improving their energy efficiency. The importance that companies attach to reducing costs in general, and energy costs in particular, varies greatly however.

To some extent, the level of companies' concern about energy is proportional to energy's share of total production costs (see figure 2-8). In industries such as steel, aluminum, cement, and industrial gases, where energy is a major portion of total costs, concern about energy efficiency is high. The existence of energy-efficiency "champins,' enlightened management, or efficiency promotion programs can also give energy a high profile in corporate decisionmaking. For example, Dow Chemical's Louisiana Division has a very successful contest for identifying and funding energy efficiency projects (box 4-A). Sudden energy price shocks or availability problems can also prompt companies to improve their energy efficiency.

The above cases notwithstanding, cutting energy costs via technical means is not a high profile concern in most industrial companies. Energy costs do not command the attention of senior management and do not garner the resources needed to implement improvements. Even in the operations divisions of firms, where cost issues are most focused, energy is but one of many concerns. An operations manager's top priorities are keeping the production line up and running smoothly, making products that meet consumer's specifications and expectations, and meeting regulatory guidelines. Energy costs tend to be secondary concerns. The general lack of concern afforded energy in many corporations is a major barrier to the implementation of energy-efficiency improvements.

Low energy awareness is less of a setback to efficiency in situations where there are new technologies with production benefits in addition to energy saving characteristics. Fortunately, many technologies fall into this category. They are implemented primarily to boost product quality, further automate production, or enhance some other characteristic. They improve energy efficiency as a side benefit. For example, continuous casting is put into steel mills primarily to improve material yields and product quality and to shorten processing times. Secondarily, the improved design of the process uses less energy per ton of steel produced.

Role of Information

Convenient information regarding new technologies and their energy characteristics is vital to efficiency implementation. Managers, especially those in small firms, do not have the time and resources for gathering and analyzing large amounts of information to support their decisions. This is particularly true when equipment fails and needs immediate replacement. There is little time to research the best available replacement technologies, and then test and tune them up once they arrive. Replacements are needed quickly, and must have minimal startup problems. Consequently, in these situations, managers usually stick with the technologies that they know well—the ones that were used before.

Providing information is a role that State and Federal Government are involved in. Utilities are also involved in disseminating information as well as conducting audits to inform companies about energy saving opportunities. Sometimes such outside organizations are successful in promoting energy efficiency technologies, because they can better deal with issues that straddle bureaucratic boundaries within fins.

Technical and Economic Feasibility

Lastly, technologies must be technologically and economically feasible to be implemented. Technologies must not only work successfully, but also be reliable, serviceable, and proven. In addition, they must be economical with respect to initial capital outlays, energy and other input prices, and costs of capital. In addition, there are various hidden costs, such as operator retraining, equipment testing and adjustment, and process downtime during installation and startup, associated with getting a technology up and ruining. These hidden costs can be sizable, but are often overlooked.

TECHNOLOGICAL FEASIBILITY

On the technical side, risk can be a large barrier to new technology implementation. Many companies are very risk averse and only invest in

Box 4-A—Dow Energy/Waste Reduction Always Pays (WRAP) Contest[1]

The Louisiana Division of Dow Chemical Co. sponsors an annual contest to generate ideas for improvements in energy use, product yield, maintenance, and waste reduction. When the contest started in 1981, it covered only energy saving projects that cost less than $200,000 and paid for themselves within a year. The scope of the contest was expanded to include product yield projects in 1983, maintenance projects in 1986, and waste reduction projects in 1987. Today, the Energy/WRAP Contest accepts any project within this scope that saves more than $10,000 year and has a return on investment (ROI) greater than 30 percent.[2]

Employees submit ideas for cost savings to the Energy Evaluation Committee. Each submission-intentionally kept simple-must include a brief project description, a summary of utility (e.g., electricity and steam) and yield savings, ROI calculation, before-and-after sketches, and if applicable, the type and quantity of waste reduced. The incremental costs for utilities and the formula for calculating ROI are published on the entry forms, so individuals can determine for themselves whether they have a good project. After an initial review of the entries, four or five members of the Committee discuss the proposals with the submitters. This review process is designed to evaluate projects, not people. The purpose is to ensure that all approved projects are technically viable and have a high probability of being successful. Winning individuals and teams are recognized through a formal awards presentation, where they are presented plaques by the division general manager. In addition, winners receive strong management and peer recognition in their own plants and departments. No monetary awards are given by the Energy Evaluation Committee to winning projects. Instead, supervisors are asked to put each individual's contest participation in the context of overall job performance and reward him or her accordingly. Later, the completed projects are audited to verify that each project accomplished what it was supposed to. The objective is not to find fault with unsuccessful projects, but to learn what makes good projects.

Between 1982 and 1988, there were 404 winning projects costing a total of $68 million. The average ROI each year varied between 77 and 340 percent. All but four of the projects had costs less than $2 million. In 1988, the 94 winning projects costing less than $2 million each required expenditures of $9.3 million and generated savings of $18 million per year. The savings came from fuel use (23 percent), product yield improvements (60 percent), capacity increases (14 percent), and maintenance (3 percent). The contribution of waste reduction projects is included in the product yield improvement category. From 1982 to 1991, more than 100 trillion Btus of energy have been saved. Dow credits the success of the program to the following elements.

- Top *management* support-The contest seeks out cost-effective projects and has low overhead. It does not require a new department, redeployment of people, or a million dollar budget.
- Employee recognition-Credit for thinking of, developing, and implementing projects goes to the submitters and their plants, not to the contest or to the Energy Evaluation Committee.
- Funding-The Energy Evaluation Committee does not directly control the allocation of capital. The contest's high credibility and demonstrated past performance lead to funding within normal budgeting and capital allocation procedures,
- *Minimal paper work.*
- *Learning* experience--The contest develops and strengthens skills such as uncovering and analyzing plant problems, calculating potential savings, developing viable solutions, estimating project costs, and making presentations.
- IIdea sharing-Descriptions of every project, winners and nonwinners, are published and distributed throughout the division.
- No conflicts with plant priorities objectives-Many of the plants reexamine their priorities as part of their contest activities.
- No numerical goals-The contest does not set numerical goals such as the number of projects submitted or dollar savings. The overall objective is to encourage continuous improvement.

---

[1] Kenneth E. Nelson, "Are There Any Energy Savings Left?" *Chemical Processing,* January 1989. Kenneth E. Nelson and Joseph A. Lindsly, "Case Study: Winning Ideas Reduce Waste at DOW," *Pollution Prevention Review,* spring 1991.

[2] ROI calculated as annual savings or earnings X 100 / project cost.

technologies that have been proven on an industrial scale elsewhere. This aversion to risk may come from management itself or imposed on it by outside providers of financing. Regardless, many companies do not like to be the first to try expensive new process technologies. There are, of course, exceptions. Nucor recently built a new steel mill in Indiana around a thin-slab casting technology that was very unproven.

Companies also want technologies to be very reliable, because of the great costs associated with malfunctions in processing lines. For example, many companies place very high premiums on the proven reliability of a certain type of pump or fan and its manufacturer; on minimizing spare parts inventories; on simplifying maintenance; and on timely delivery of spares. They are often unwilling to switch to a different manufacturer to get a slightly more efficient pump or fan for a specific application.

Other important considerations in energy decisionmaking are the connections between energy-using technology and product quality, yield of materials, maintenance of equipment, capacity of production, and so forth. Energy conservation measures are not undertaken if managers believe that the new technologies are likely to interfere with production in any way.

ECONOMIC FEASIBILITY

Standard accounting procedures can be used to evaluate the economics of all the technical factors, including the risk, mentioned above. However, the evaluation process itself can be costly and burdensome. Small projects are therefore often evaluated solely on their initial capital outlays and cost savings (box 4-B). Factoring in the risk, hidden costs, and other difficult to quantify costs and benefits occurs through managerial intuition.

CAPITAL AND PERSONNEL AVAILABILITY

Funding is another major impediment to implementing energy efficiency improvements. Two general classes of projects, mandatory and strategic, usually have the highest -claims on companies' available investment capital, Mandatory projects focus on regulatory compliance, capitalized maintenance, replacement of essential equipment, and maintenance of product quality. Strategic projects are market development activities, such as market share enhancement, new product development, capacity expansion, and acquisitions.[3] Though discretionary, strategic projects are high priority uses of finds.

The amount of capital left over for lower-priority discretionary projects such as energy efficiency improvements and other cost cutting efforts is often small. Getting funding for energy projects can, thus, be much more difficult than the standard evaluation criteria (e.g., simple payback, internal rate of return, and net present value) would suggest. In a 1983 survey of project funding practices in large industrial firms, the Alliance to Save Energy found that many firms use capital rationing as a project funding control mechanism.[4] Under capital rationing, projects compete among themselves for a freed amount of discretionary capital, and some projects that are otherwise economically attractive do not get funded if the capital pool is too small. For firms that manage capital in this manner, the de facto internal cost of capital for discretionary projects can be extremely high, making many projects appear unattractive.

In addition to the scarcity of capital for efficiency projects, there is often a shortage of technical personnel. With many companies running as lean as possible, engineers and technicians are kept busy making sure the production lines run smoothly and in compliance with

---

[3] Alliance to Save Energy, *Industrial Investment in Energy Efficiency: Opportunities, Management Practices, and Tax Incentives,* July 1983.

[4] Ibid.

Box 4-B–Evaluating a Project's Financial Worth

Various methods are used to calculate the financial worth of a project to a company. They all attempt to measure the net monetary effects of a project's costs and benefits over its useful life. The costs include capital outlays, operating and maintenance disbursements, startup downtime, etc. The benefits include improved product quality, increased productivity y, energy savings, etc. Three of the more common project evaluation techniques are simple payback, return on investment, and net present value. Companies choose the technique that best reflects their management style and accounting practices.

Simple payback, the crudest measure, is the time in years for cumulative cash flow (net benefits) to equal the project's capital cost. This method essentially measures the time it takes for a project to pay for itself. For example, a $600,000 investment that returns $200,000 per year "pays back" in 3 years. Generally, low payback periods make projects attractive investments. Many firms are reluctant to invest in projects with paybacks greater than 2 or 3 years. However, this cutoff varies widely not only by company, but also by project size.

The more sophisticated evaluation methods, return on *investment (ROI)* and net *present value (/VPV),* explicitly take the time value of money into account. They compare a project's worth to that of other investments (including no-risk financial instruments). ROI is the discount rate that equates the value of estimated future cash flows (net benefits) arising from an investment with the initial capital outlay. NPV is the value of the future cash flows (discounted at a set rate) minus the initial capital outlay. High ROIs or NPVs make projects attractive for investment. Depending on the company and the size and risk of the investment, typical industrial projects must have ROIs of at least 15 to 30 percent to be considered attractive. Projects with 30 percent ROIs typically have paybacks in the 3 to 4 year range. The following table shows equivalent ROIs for various payback periods and project durations.

Payback and annual return on investment conversion table[1]

Payback period (years)	Project lifetime (years)				
	5	7	10	20	40
1	159%	161%	161%	161%	161%
1.5	86	90	91	91	91
2	55	60	63	63	63
2.5	37	44	47	48	48
3	25	33	37	39	39
3.5	16	25	30	32	33
4	10	19	25	28	28
4.5	4	14	20	24	25
5	0	11	17	21	22
6	—	5	12	17	18
7		0	8	14	15
8		—	5	12	13
9			2	10	12
10		—	0	8	10

[1] Annual return on Investment is calculated based on a stream of equal monthly savings or benefits. For Example, a project that costs $24 and yields $1 of benefits each month for 5 years has an ROI of 55 percent (and a payback period of 2 years).

The process of estimating a project's future cash flows for ROI and NPV analysis can be very sophisticated. It may include assumptions and forecasts regarding the project's technical performance, the product's market and prices, the prices of inputs (e.g., energy, raw materials, and labor), interest rates, depreciation rates, tax rates, etc. The evaluation may be further enhanced by analyzing the effects of uncertainties regarding the various factors (i.e., sensitivity analysis) and accounting for business and technical risks. Highly sophisticated evaluations can require very costly information are therefore used only for very large projects. For smaller projects, rule-of-thumb assumptions are often made for many of the factors,

SOURCE: Office of Technology Asessment, 1993.

government regulations, These personnel are concerned primarily with the business' core activities and have little time left for discretionary concerns. Hiring additional personnel or using outside consultants to alleviate shortages of technical expertise can be expensive. Costly training is required to fully acquaint the new engineers and technicians with equipment and production processes. Furthermore, these employees become burdensome overhead if the business has to cut back to the core activities during economic hard times, Companies are reluctant to routinely hire and lay off engineering personnel through business cycles, partly because it fosters a reputation that makes attracting top-flight technical talent difficult. Using outside consultants to implement discretionary projects can also present problems. Consultants require a great amount of technical and contract oversight, and if proprietary processes are involved, may represent an unacceptable security risk.

ENERGY PRICES

Rising energy prices increase energy awareness and improve the economic feasibility of efficiency projects.5 Likewise, declining prices cause energy awareness to wane. Because implementing a new technology saves energy in the future, companies are more sensitive to expectations of future energy prices than to the current prices in their investment decisions.6

The Efficiency Gap

There is much anecdotal evidence of industrial companies failing to undertake energy-saving projects that are presumably cost-effective. Industrial managers want energy efficiency projects to pay back very quickly, often in 2 years or less.[7] A payback period of 2 years represents an internal rate of return of about 60 percent, a rate much higher than the market cost of capital (box 4-B). Projects that have rates of return between the market cost of capital and the much higher internal threshold rate are presumably cost-effective, yet not undertaken. These projects fall into what has been called the ''efficiency gap. "

The efficiency gap is caused by features such as: lack of information, uncertainty about fuel prices, uncertainty about investment benefits (i.e., equipment performance), misplaced managerial incentives, and equipment supply infrasructure problems. Industrial managers often cite lack of funds and technical personnel (discussed earlier) as the reasons that many cost-effective projects are not undertaken.

Except for the personnel aspect, these same factors apply to residential investments in energy efficiency and have been studied extensively.[8] Interpretation of these conservation-inhibiting factors is a matter of some controversy. Conservation advocates generally view the factors as market barriers, and see a role for government in helping the market encourage more energy efficiency investment. Alternatively, economists see most of these factors as a reflection of competitive markets, and argue that government intervention is neither justifiable nor beneficial. From an economist's viewpoint, many projects that are presumably cost-effective are in reality not so, because of the costs associated with these factors.

---

[5] The quantitative effects of prices on industrial energy efficiency is unclear, however. See discussion under, ' 'What Role Do Energy Prices Play?" in ch. 1.

[6] Alliance to Save Energy, op. cit., footnote 3.

[7] Marc H. Ross and Daniel Steinmeyer, ''Energy for Industry, ' *Scientific American,* vol. 263, No. 3, September 1990, pp. 89-98. Winslow H. Fuller, XENERGY Inc., "Industrial DSM—What Works and What Doesn't, " *Proceedings of ACEEE 1992 Summer Study on Energy Efficiency in Buildings* (Washington DC: 1992).

[8] Roger S. Carlsmith, William U. Chandler, James E. McMahon, and Danilo J. Santini, Oak Ridge National Laboratory, *Energy Efficiency: How Far Can We Go?* Report No. ORNLfI14- 11441, January 1990. Richard B. Howarth and Bo Andersson, Lawrence Berkeley Laboratory, "Market Barriers to Energy Efficiency, " Paper No. LBL-32541, July 1992. Ronald J. Sutherland, "Market Barriers to Energy-Efficiency Investments," *The Energy Journal,* vol. 12, No. 3, 1991.

INDUSTRIAL COMPANIES AND UTILITIES

Fuel Flexibility

As mentioned earlier, companies see energy in terms of cost. They have incentives not only to become energy efficient, but also to seek out the lowest priced, most secure energy sources. To obtain low energy prices and a margin of safety in terms of reliability, companies (especially energy-intensive ones) prefer to be as flexible as possible in their fuel use. The ability to easily switch to alternative fuels protects companies against severe energy price fluctuations and supply cutoffs. It also increases companies' bargaining power with their utilities. For example, by threatening to install cogeneration capacity, companies can push for more favorable power contracts from their utilities.

While fuel flexibility can save companies money, it may come at the expense of lower energy efficiency. Processes designed for multiple fuels are sometimes not as efficient as those designed for a single fuel. Moreover, investments made for fuel flexibility purposes use up funds that could be used for energy conservation or efficiency projects.

Industrial Companies as Energy Producers

In addition to being energy consumers, companies in several industries (e.g., pulp and paper, chemicals, and petroleum refining) are large energy producers. They, or third-party partners, produce electricity with cogeneration facilities, and sell to the grid whatever power they cannot use at the plants. The electricity sales can be a large source of revenues. As energy producers, these companies have a great deal at stake in the many rules governing electricity generation, transmission, and distribution. For example, two changes that many large industrial companies would like to see are: 1) being able to sell their power to retail customers (retail wheeling), and 2) being able to transfer power from one of their plants to another over the grid (self-wheeling). Currently, neither of these practices is allowed. Access to the electricity market affects the value of cogenerated electricity and thus the economics of constructing cogeneration facilities. Increased access to electricity markets increases the overall cogeneration potential of industry.

Demand-Side Management[9]

Demand-side management (DSM) is the planning, implementation, and monitoring of utility activities intended to modify customers' patterns of energy use. The utilities' interest in such programs is to achieve a better balance between the supply and demand for their power. By more closely matching the timing and level of their demand load with the available supply, utilities are better able to control their costs and rates. For utilities, facilitating energy savings may be less expensive than adding new supply capacity. Currently, DSM is practiced principally by electric utilities, but such programs do exist at some natural gas utilities.

Utilities have special interest in their industrial customers for several reasons. Industrial companies are large energy users that represent a major part of utilities' baseload. Indeed, most large industrial customers receive lower rates because they supply utilities with large, dependable portions of electricity demand. As large individual power loads, industrial plants also represent highly concentrated sources of load shape modification potential for utilities. In a similar vein, industrial DSM programs require fewer resources to effect a given amount of energy savings than do programs in the residential and commercial sectors, This is because industrial projects are larger, and relatively few people need to be involved to save large amounts of energy. Lastly, utilities want their industrial customers to be competitive

---

[9] A comprehensive look at demand-side management is presented in U.S. Congress, Office of Technology Assessment, *Energy Efficiency: Challenges and Opportunities for Electric Utilities*, OTA-E-561 (Washington DC: U.S. Government Printing Office, in press).

and financially healthy because of the jobs they provide, in the plants themselves and in the communities at large. This employment is important for sustaining the utilities' residential and commercial markets.[10]

Despite the advantages of industrial DSM, it has lagged behind its counterparts in the commercial and residential sectors. The ''diversity and complexity of industrial energy uses, limited utility experience with industrial processes, and the scarcity of industrial DSM demonstrations have combined to inhibit the implementation of industrial-sector DSM. ' '[11]

There are several major types of DSM programs that utilities use to influence the energy decisions of their industrial customers. These include: alternative pricing, customer education and advertising, trade ally cooperation, direct customer contact, and direct incentives.[12] Alternative pricing is the most common industrial DSM approach, but more and more utilities are assuming more proactive marketing and technology oriented roles.[13]

ALTERNATIVE PRICING

Utilities have traditionally relied on alternative rate designs such as time-of-use, interruptible, promotional, and variable level-of-service pricing to achieve industrial sector DSM objectives.[14] These incentives have produced the largest changes in industrial load shape for most utilities. New rate programs can be difficult to establish, however. They require review and approval by regulatory commissions.

Many companies have complex power contracts with their electric utilities. Charges are incurred for energy use (kilowatt-hour), energy demand (kilowatt peak), power factor, and various other electricity characteristics. In addition, the rates may vary by time of day and season of the year. Such time-of-use rates can be used to encourage companies to shift their energy use to off-peak periods such as the nighttime. An example, is for textile mills to run their chillers only at night (instead of all the time) and store the cool water for use during the day. These time shifts may not actually conserve energy, but they lower its costs.

EDUCATION AND ADVERTISING

Utility promotions, publicity, direct contact, advertising, and field tests and demonstrations perform valuable functions in companies' need for technology information. Advertising and/or education programs are particularly valuable for generating interest in DSM programs and technologies. Field tests and demonstrations of new technologies are receiving increasing interest. The purpose of such programs is to obtain and disseminate information on the cost, performance, reliability, and operational characteristics of the technologies. The Bonneville Power Administration (BPA) and the Tennessee Valley Authority (TVA) have active field testing and demonstration programs. The programs at BPA have included efficient aluminum smelting cathodes, adjustable-speed drives, and a pulp-refining process. At TVA, the programs have included thermal

---

[10] Electric Power Research Institute, 1990 *Survey of Industrial-Sector Demand Side Management Programs,* EPRI CU-7089 (Palo Alto, CA: Electric Power Research Institute, January 1991).

[11] Electric power Research Institute, ***Industrial LoadShaping:*** *An IndustrialApplication of Demand-Side Management,* EPRI CU-6726 vol.1 (Palo Alto, CA: Electric Power Research Institute, May 1990).

[12] Electric Power Research Institute, *Demand Side Management, vol. 5: Industrial Markers and Programs,* EPRI *E@ M-3597* (Palo Alto, CA: Electric Power Research Institute, March 1988).

[13] EPRI CU-7089, op. cit., footnote 10.

[14] EPRI Cu.1'egg, op. cit., footnote 10.

storage systems, biomass cogeneration units, energy efficient motors, and microwave driers.[15]

TRADE ALLY COOPERATION

Trade allies are firms, individuals, or organizations that can influence the relationship between companies and their utilities. Trade allies can be helpful in promoting energy efficient technologies to companies during critical decision phases of projects. For example, utilities may provide technology and design information to architectural and engineering (A&E) firms that design and build industrial facilities.

DIRECT CUSTOMER CONTACT

Most utilities contact their large industrial customers two or more times a year. The frequency with smaller firms is usually lower. As part of the effort, utilities may offer audits, engineering assistance, and/or feasibility studies. Some utilities offer audits to all industrial customers, others just to small customers. The reason for targeting small industrial customers is that they often lack the in-house engineering staff, knowledgeable about energy saving practices and relevant DSM technologies, that large companies have. The engineering services offered by utilities range from drafting equipment installation proposals to designing, installing, and maintaining equipment, Continued contact with the industrial customer allows the utility to:

- Identify and describe opportunities for efficient energy use and energy cost savings;
- Answer any problems or questions related to energy utilization, supply, or billing; and
- Advise customers on technologies for improving productivity and competitiveness.

DIRECT INCENTIVES

Utilities use a variety of financial incentives to “discount” the purchase cost and improve the internal rate of return of companies’ efficiency investments, Such incentives include: loans (ranging from interest-free to full-market rate), lease and purchase agreements, rebates, allowances, and buy-back or shared savings programs. A variation of this strategy is to offer the incentive to only one company in exchange for demonstrating the technology, so that other companies might become interested.[16]

Motors programs are among the most common of the direct incentives initiatives. Most promote the use of high-efficiency motors in new motor applications and as replacements for burned-out old motors, A few also promote adjustable-speed drives. The rebates are designed to cover most of the cost difference between an efficient motor and a standard motor. Minimum qualifying efficiencies are specified for each standard horsepower rating.

Motor programs have generally had very low participation rates. Among the reasons have been:[17]

- Customers’ bad early experiences with high-efficiency motors due to improper sizing and installation;
- Unfamiliarity of customers and dealers with the substantial operating cost savings available with high-efficiency motors;
- Multiple decisionmakers on motor purchase decisions and difficulties in reaching the right decisionmaker;
- Customer hesitancy to shut down production lines to replace an operating motor;

---

[15] EPRI EA/EM-3597, op. cit., footnote 12.

[16] The National Industrial Competitiveness through efficiency: Energy, Environment, and Economics (NICE^3) grant program, run by the Department of Energy and the Environmental Protection Agency uses a similar strategy (see ch. 1).

[17] American Council for an Energy-Efficient Economy, *Lessons Learned: A Review of Utility Experience With Conservation and Load Management Programs for Commercial and Industrial Customers*, April 1990.

- A tendency by many customers to speed up motor replacements by replacing burned-out motors with identical motors, and to both speed replacements and cut capital costs by rewinding burned-out motors instead of replacing them; and
- Low rebate levels that cover only a portion of the cost of new, high-efficiency motors.

DSM: Rate and Equity Concerns

Some industrial energy users worry that DSM will ultimately raise electricity prices.[18] They argue that there is great uncertainty in the program costs and conservation benefits of DSM, and that the programs may well cost too much for the energy savings that they actually deliver. Because of the costs of DSM programs and the reduced rate base, electricity rates may increase.

There are also equity issues associated with DSM. Is it fair for a company to invest in an energy efficiency project with its own capital and later have its utility help fund a similar project at a competitor's plant?[19] This may forestall investment, as companies delay programs in order to see what DSM incentives may be offered to them. Another issue is cross-class subsidies. Should industrial customers be made to pay higher rates to cover the program costs of residential and commercial DSM programs.

One utility, Niagara Mohawk, has begun to address some of these concerns, It has an experimental conservation rebate program that allows industrial customers to pay slightly lower rates if they forgo the rebates. Under the program, an industrial company must pay for up-front conservation audits, then decide whether or not to implement the recommended conservation measures and give reasons for its decision. The utility will put up the initial capital to implement the audit recommendations and will be repaid out of the energy savings. Companies that decline the utility's offer for capital and ''opt out' out of the program get to pay $.015 per kWh less for their electricity. All companies, though, even those that "opt out," must cover 60 percent of the conservation program's cost.[20]

DSM: Experience to Date

In a recent survey, the Electric Power Research Institute identifiled 417 industrial-sector DSM programs conducted by 154 utilities.[21] Table 4-2 shows the general classes of DSM programs pertinent to the industrial sector and their reported load impacts. These programs have involved nearly 50,000 industrial customers. Some of the programs are designed exclusively for industrial customers, but more than half also apply to commercial customers, and many are designed primarily for the commercial sector.

Another survey, by the American Council for an Energy-Efficient Economy (ACEEE), found that industrial DSM programs focus primarily on equipment upgrades such as high-efficiency motors and lighting systems.[22] Few programs focus

---

[18] One group espousing this viewpoint is the Electricity Consumers Resource Council (ELCON).

[19] These issues of equity do not, however, apply to competitors in different utility service areas, which presumably have different rates anyway.

[20] David Stipp, "Some Utilities' Plans to Cut Energy Use Cost More and Save Less Than Projected, " *The Wall Street Journal,* May 27, 1993. "Industrials Can 'Opt Out': Who Won, Who Lost in New York's New Shared Savings Experiment?, " *The Electricity Journal,* January/February 1993.

[21] EPRI CU-7089, op. cit., footnote 10.

[22] Jennifer A. Jordan and Steven M. Nadel, American Council for an Energy-Efficient Economy, ''Industrial Demand-Side Management Programs: What's Happened, What Works,'' *Proceedings of ACEEE 1992 Summer Study on Energy Efficiency in Buildings* (Washington, DC: 1992).

Table 4-2-industrial Demand-Side Management Programs

Technology category	Peak load reduction (kW/participant)	Load addition (kW/partlclpant)	Program features
Audit and building envelope	188		**Industrial energy conservation, building shell improvements, facility energy analyses, productivity audits, and process efficiency assessments.**
Heating, ventilating, and air conditioning (HVAC)	1.0 to 3.6	56.6”	**Electric space heating, space cooling, ventilation, and air-quality equipment.**
Lighting	12.3 to 23.0	4.8’	**Efficient lamps and fixtures, task lighting, outdoor lighting, and lighting control systems.**
Electrotechnology	54.8 to 7,500[b]	753.6 to 1,000	**Promotion or testing of electric-driven technologies that support industrial** processes.
Thermal storage	22.0 to 2,1 00’	—	**Storage space heating, storage water heating, storage air-conditioning, and storage refrigeration systems.**
Load control	12.0 to 383	—	**Utility control of customer loads or the promotion of facility energy management systems.**
Economic development		162 **to** 5,800[d]	**Efforts to attract industry to, or retain industry within, an area by offering enhanced services or by implementing competitive pricing strategies.**
Special rate	24.6 **to** 85,400[d,e] 32.9 **to** 7,000[c,d]		**Offering nonstandard industrial rates, such as interruptible or time-of-use rates, that are not associated with specific technologies.**
Standby generation	242 to 8,000[d]		**Promotion of customer cogeneration or utility-dispatchable standby generation equipment located at the customer site.**
Motor and motor drive	1.0 **to** 76.3[b,d]	19,500	**High-efficiency motors and/or electronic adjustable speed drives.**
Power quality and conditioning	[f]	[f]	**Equipment for decreasing power disturbances or controlling power conversions or utility services designed to solve customer power quality problems.**

[a] Designated as off-peak.

[b] Reported as equipment operating demand reduction in some cases.

[c] Reported as **load shifted off-peak.**

[d] Includes commercial **customers.**

[e] Reported as contracted interruptible load.

[f] Data not reported.

SOURCE: Electric Power Research Institute, *1990 Survey of Industrial-Sector Demand-Side Management Programs,* **Report No. EPRI** CU-7089 **(Palo Alto, CA: Electric Power Research Institute, January 1991).**

on improving the efficiency of entire manufacturing systems or processes. Roughly 60 percent of the programs surveyed offer custom measure incentive programs, such as:

- cash incentives for the incremental cost of efficient equipment,
- incentives based on energy saved or load reduced in first year (i.e., $/kWh or kW saved),
- rebates based on a percentage of materials and installation costs,
- cash grants,
- low-to-no-interest loans, and
- payback period buy-down incentives.

The most frequently covered investments are process heating and cooling measures, refrigeration improvements, and lighting and motor upgrades. About 40 percent of the programs are prescriptive measure rebates, which generally offer direct rebates for installation of high-efficiency motors, steam traps, adjustable-speed drives, and compressed-air system improvements. Rebates are calculated in terms of either dollars per unit of energy saved or percentages of project costs.

The ACEEE survey found that while a few programs had achieved significant savings and participation, on average the programs have had little impact. The average program is almost 4 years old, has seen participation by about 6 percent of the utility's industrial customers, and has cumulatively saved less than 0.4 percent of the utility's industrial energy sales at a levelized cost of $.012/lcWh. Examples of some of the more successful, or more innovative, industrial DSM programs reported in the ACEEE survey are presented in box 4-C.

Box 4-C-Examples of Industrial Demand-Side Management Programs[1]

Bonneville Power Administration: Aluminum Smelter Conservation and Modernization (Con/Mod) Program and Energy Savings Plan[2]

The Bonneville Power Administration's (BPA) Con/Mod program is the largest industrial demand-side management (DSM) program in the Nation. BPA pays the 10 participating aluminum smelters $.005 (in 1985 dollars) for each kilowatt-hour that they save through efficiency improvements. The program was begun in 1987 and was planned to last for 10 years. The near-term objective was to modernize the aluminum plants so that they would be economically viable even when aluminum prices are low. The long-term objective was to give BPA low-cost conservation by requiring Contract Demand reductions (decreases in total contract power entitlements) for the modernization projects completed by June 30, 1991? In fiscal year 1992, the program saved an average of 107 MW. Savings over the lifetime of the program have been about 4.1 percent of BPA's industrial sales. In an associated effort, the Variable Rate program, BPA offers electricity to the smelters at rates tied to the price of aluminum. BPA's Energy Savings Plan is targeted at smaller industrial customers. This custom rebate program pays customers $.15 per kilowatt-hour saved in the first year or 80 percent of the project costs, whichever is smaller. The program has saved about 5.5 percent of BPA's nonaluminum industrial sales.

Central Maine Power: **Power Partners and Efficiency Buy-Back Programs**

The Power Partners program offers energy management contracts paying $,01 per kilowatt-hour of delivered savings. Commercial and industrial customers, as well as energy service companies, are eligible to bid on these

---

[1] Except where noted, taken from Jennifer A. Jordan and Steven M. Nadel, American Council for an Energy-Efficient Economy, "Industrial Demand-Side Management Programs: What's Happened, What Works," *Proceedings of ACEEE 1992 Summer Study on Energy Efficiency in Buildings* (Washington, DC: 1992) and *Industrial Demand-Side Management Programs: What's Happened, What Works, What's Needed,* prepared for the Pacific Northwest Laboratories of the U.S. Department of Energy, DOE/EE/01830-H1 (Washington, DC: March, 1 993).

[2] Bonneville power Administration, Office of Energy Resources, Business Services Branch, *Aluminum Smelter Conservation/Modernization Program, FY 1992 Year End Report,* January 1993.

[3] During fiscal year 1992, BPA and the smelters agreed on a Contract Demand Reduction amount of 124.6 annual average MW.

contracts. Over its lifetime, the program has saved 1.2 percent of industrial sales and 7 percent of the eligible customers have participated.

The Efficiency Buy-Back program targets larger customers and provides incentives of up to 50 percent of project costs. Proposed projects must save at least 5 GWh per year. The program has achieved savings of about 0.9 percent of industrial energy sales with low participation at low cost.

Wisconsin Electric: Smart Money for Business Program

This combination custom and prescriptive rebate program offers commercial and industrial customers a wide variety of incentives for efficient motors, lighting, and process equipment. Over its lifetime, the program has saved 2.5 percent of industrial energy sales at a cost of about $.021 per kilowatt-hour saved. Nearly half of the utility's industrial customers have participated in the program. The program was refined after 3 years to improve the communication with the industrial consumers. Now, utility engineers communicate with process-level personnel, such as plant engineers and maintenance operators, for smaller projects. Simultaneously, utility executives interact with industrial vice presidents for larger projects.

Puget Sound Power and Light: Industrial Conservation Incentive Program

This program, which targets the 100 largest industrial customers, offers incentives of $.02 to $.15 per kilowatt-hour saved in the first year of efficiency projects. The incentive covers about 50 to 80 percent of projects costs. The program is a very labor-intensive, full-service program. Utility personnel work with participants to analyze entire industrial systems, identify where energy and other benefits lie, oversee project bidding, assist in project design and planning, and perform energy-savings verification tests. Over its lifetime, the program has saved 2.0 percent of industrial energy sales at a cost of about $.015 per kilowatt-hour saved.

United Illuminating: Energy Opportunities Program

This program co-funds engineering studies of advanced process, energy management, cogeneration, and heat recovery measures for industrial and commercial customers. The financial incentives for project implementation are based on the projects' costs and payback periods. Incentives of $.15 per kilowatt-hour saved in the first year are offered for measures with payback periods greater than 5 years, Measures with shorter payback periods receive rebates as a percent of project cost, with rebates declining as the payback period decreases. After 2 years, the program had a large portion of the program budget remaining so the maximum incentive was doubled to $.30 per kilowatt-hour saved in the first year. Over its lifetime, the program has saved 1.2 percent of industrial sales and 3.2 percent of the eligible customers have participated. The utility cost for the program has been $.014 per kilowatt-hour saved.

Southern California Gas: High-Efficiency Industrial Equipment Replacement and Industrial Heat Recovery Programs

These programs are examples of natural gas DSM efforts, which are currently much less common than electric DSM activities. These programs offer industrial customers incentives to perform consultant studies and install efficient equipment. The measures most commonly funded are installation of high-efficiency boilers and burners in the efficiency program and economizers and recuperators in the heat recovery program.

Pacific Power and Light: Energy Finanswer Program

This newly-created program offers industrial customers loan financing rather than cash rebates for energy-efficiency improvement projects, The utility offers to pay 100 percent of the cost of design and implementation of a cost-effective, energy-saving project upfront, with the customer paying back the utility at the prime interest rate plus 2 percent over a period of 5 to 10 years. Customers must have a load of at least 500 kW to participate in the program. Recently, the utility has added a guaranteed savings feature to the program format.

Appendix A:

Funding of DOE, Office of Industrial Technologies Research and Development Program

Appendix-A—Funding of the U.S. Department of Energy, Office of Industrial Technologies Research and Development Program

Program	Examples of projects in FY 1993, budget authority in ($ thousands)	FY 1992 enacted	FY 1993 enacted	FY 1994 requested
		(millions of dollars)		
Industrial wastes Waste utilization and conversion	Recovery of marketable plastics, metal, and fiber fuel from automobile shredder residue (2,000). Expansion of markets for surface-activated waste tire rubber (1 ,053). Conversion of tire rubber, mixed plastics, sludges, and wood and/or paper wastes to plastics (1 ,000). Bio-reactor for acetic acid production (700).	$5.9	$7.9	$11.1
Waste minimization	Reduction of: byproduct wastes in oxygenated chemicals production; metal ions in plating wastes; VOCs and CFCs in super-critical parts cleaning; and CFCs in circuit board soldering (2,790). Reduction of wastes in chemicals, chemical-using, and petroleum industries (2,300). Production of hydrogen and sulfur from hydrogen sulfide wastes; UV dual cure coatings process; reduction of wastes and emissions in silicon and ferrosilicon production; reduction of amine use in removing $C0_2$from raw natural gas; and removal of VOCs from waste gas streams using membrane technology (1 ,578). National Industrial Competitiveness through efficiency: Energy, Environment, and Ecmomics (N ICE^3) program (1 ,500).	7.3	9.6	15.9
Municipal solid wastes Waste combustion	Sewage sludge and MSW burning technologies; natural gas reburn and lime injection to reduce acid gas emissions; and direct injection of chemicals to meet chlorine and sulfur emissions standards.	0.6	0.7	0.7
Waste data collection	Development and dissemination of energy, economic, environmental, safety, and health data on MSW processes such as Waste Thermal Energy plants and material-recovery facilities.	1.0	2.3	2.2
Cogeneration Advanced topping cycles	Ceramic components for retrofit into stationary gas tubines (3,222) Increased electricity generation from simple back pressure steam turbines (555).	3.2	4.5	9.2
Electric drives	Determine R&D requirements on electric motor systems (1 68). Initiate and organize multi-party program to demonstrate energy -efficient motor drive systems (163). Assist in establishing a training program on motor and drive selection in two resource centers (155).	—	0.7	2.1
Materials processing Metals initiative	Experimental program for direct ironmaking; design manual to support commercialization of direct iron/steelmaking; feasibility study to define concept and configuration of a demonstration plant (8,550). Sensor probe to rapidly determine chemical composition of molten iron and steel (1,419). Single-wheel thin strip steel caster, using open channel process (984). Improved cathodes for aluminum smelting (708).	17.5	17.9	19.4
Process electrolysis	Cell design, scale-up, control, and operating procedures for aluminum reduction cells based on cermet inert anodes (841). Metal ceramic inert anodes for magnesium production (430). Electrolytic method to produce neodymium metal from an oxide feed (216).	1.0	1.5	1.5

Foundries and glass	Inventory management system for coils of cold rolled sheet steel as part of "Integrated Manufacturing Information Systems" (2,975). Ultrasonic inspection and electromagnetic filtration to detect and eliminate defects in castings and increase production yield (1 ,487). Identify barriers to implementation of best available technologies for energy reduction in metals, glass, cement, and refractory industries (1 ,035). Rapid glass refiner (464).	6.7	6.4	9.0
Separations Membranes	Hybrid distillation/facilitated transport membrane system for separation of propane and propylene (930). Catalytic ceramic membrane reactor to ethylbenzene or isobutane dehydrogenation (671).	1.8	1.9	—a
Pulp and paper	Black liquor pulsed combustion and gasification (2,377). Black liquor recovery boiler computer model (663). Demonstration of hot solids firing of black liquor (470). Develop programs to address technology needs for the pulp and paper mill of the future (132).	2.8	3.9	6.2
Food, chemicals, textiles, and agriculture	Disseminate strategic R&D and management plan for Alternative Feedstocks Utilization Programs and initiate R&D on high-volume, starch-to-chemicals processes (2,280). Develop programs to address technology needs for the petroleum refinery and textile industry of the future (250).	1.0	2.5	6.8
Sensors and controls	Sensors and controls for various pulping and papermaking process parameters (1 ,215). Sensors and controls for various agriculture and food processing parameters (530).	2.4	1.8	1.8
Bioprocessing	Metal catalyst for the production of maleic anhydride; bimetallic catalysts for combustion of pollution gases; and zeolite catalysts for processing petroleum feedstocks into chemicals (1 ,786). Biocatalyst for use in both aerobic and anaerobic systems (1 ,470). Fixed-bed and fluidized-bed bioreactors for organic acids and alcohol production (1 ,000). Use of dehydrogenation, electroreduction, and methane selective oxidation reactions to produce chemicals from renewable feedstocks (600).	4.9	5.2	5.1
Enabling materials Continuous fiber ceramic composites	Processing and fabrication technologies for continuous fiber ceramic composites (4,700). Performance requirements for continuous fiber ceramic composites (2,205).	6.7	6.9	7.5
Engineered industrial materials	Develop and characterize intermetallic alloys, including aluminizes of nickel, iron, and titanium (2,672). Coordinate ceramics research and apply work to specific industrial uses; apply titanium diboride fabrication techniques to other composites; flame spraying and other coatings techniques; reactive metal infiltration composite systems; silicon carbide powder synthesis; infrared opacification of aerogels and modification of the materials for applications such as membranes, catalysts carriers, and filters (2,396). Develop and deploy composites formed by chemical vapor deposition of silicon carbide (1 ,200).	4.7	6.3	8.0

Materials manufacturing technologies	Microwave processing of glass and ceramic powders; use of conducting polymers, thin film surface modification techniques, magnetic field processing, and bimetallic coatings in membrane applications (3,086).	3.7	3.9	3.3
Improved combustion efficiency General combustion processes	Spray dynamics processes, with focus on nonpetroleum backup fuels for natural gas furnaces and process heaters (600). Control on nitrogen oxide in combustion of natural gas (400). Catalytic combustion to achieve higher heat release rate and lower emissions in gas turbines and radiant burners (395). Pulse combustors for industrial applications (385).	1.1	1.8	2.1
Engine combustion processes	Eliminate soot particles and reduce nitrogen oxide from diesel combustion emissions (1,175). Stratified charge combustion in 2-stroke engines (686). Combustion kinetics and knock in burning gasolines of the future in existing engines (525).	4.2	2.8	—
Industrial combustion equipment	Ferrous scrap preheater fueled by natural gas and oil on the scrap (1,226). Work piece temperature analyzer for use in metallurgical heat treatment and ceramic processes (1,112). Wet oxidation technology (992). Porous ceramic burner technology (666).	1.4	4.1	1.9
Process heating and cooling Heat pumps	Liquid vapor-and solid vapor-chemical heat pumps (890). Process integrated heat pumps for use by corn syrup processors, petroleum refineries, and pulp and paper mills (801).	1.9	2.2	1.7
Recuperators	Syn-gas chemical reactor unit and a unit for indirect burning of hazardous waste to operate a gas turbine (1,731).	2.4	2.3	2.7
Thermal science	Design data and performance prediction methods for use in developing enhanced surfaces for high-efficiency heat exchangers; analysis of transport mechanisms for advancing understanding of membrane separation technologies (1,477).	2.4	2.6	2.5
Implementation and deploymentt	Energy Analysis and Diagnostic Centers (EADCs) located at 25 universities (3,937). Technology transfer activities, including workshops, demonstrations, document preparation and dissemination, and other outreach activities (275).	3.5	4.5	7.5
Capital equipment		0.9	2.8	1.6
Program management		7.8	5.9	7.2
Total budget		96.7	112.8	137.1

[a] Incorporated within the food, chemicals, textiles, and agriculture area of the Separations program.

KEY: VOC = volatile organic compounds; CFC = chlorofluorocarbons; CO_2 = carbon dioxide; MSW = municipal solid waste; R&D = research and development.

SOURCE: U.S. Department of Energy, *Congressional Budget Request, FY 1994, Volume 4,* April 1993.

Index

U. S. GOVERNMENT PRINTING OFFICE : 1993 0 – 330-074 ; QL 3