ENERGY EFFICIENCY AND USE IN THE BASIC INDUSTRIES

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INTRODUCTION

The industrial sector is vital to the economic strength of the United States. In 1991, industry (including manufacturing, agriculture, mining and construction) added an estimated 1.7 trillion dollars to the U.S. economy and employed nearly 30 million people.[1] The manufacturing sector alone, with its over 360,000 facilities, accounted for over 1.3 trillion dollars of value added and 2.8 trillion dollars in products.

Energy is an essential part of all industrial activities. It is used to generate heat and steam for industrial processing, to power machine drives, equipment and tools, to provide light, heat and cooling for factories, and as a raw material in the production of chemicals, plastics, and steel. The industrial sector is responsible for more than a third of all the energy consumed in the United States every year (about 31 quadrillion British Thermal Units (Btus) in 1993), at a cost of about $130 billion (see Figure 1).[2]

Energy Use in the Basic Industries

The largest consumers of energy in manufacturing are the material and process industries, or *basic industries*, which include petroleum refining, chemicals, pulp and paper, primary metals, food processing, and stone, clay and glass. These industries account for over 85 percent of industrial energy use (see Figure 2). Basic industries use a variety of energy sources to transform raw materials into intermediate and finished industrial products -- iron to steel, wood to paper, crude oil to plastics, silicon to glass, etc. Many also make use of waste or byproduct fuels which are produced on-site, such as refinery gas, waste heat from blast furnaces, the byproducts of coke ovens, and wood waste. In the pulp and paper industry, for example, more than half of energy requirements are met by waste fuels such as bark, wood chips, and black liquor, a byproduct of pulping.

Transforming raw materials into salable products often requires chemical, physical, and biological separation and synthesis processes which consume large amounts of energy in the form of heat or electrical power. A steelmaker, for example, who begins with iron ore as a raw material, must first remove the metal from the ore, melt and refine it into steel, and then form it into sheets or ingots. Unlike the relatively simple mechanical process used to extract the ore at the mine, the processing of the raw material into a finished product involves both separation and chemical synthesis, which are very energy-intensive and generate significant byproducts or waste.

Feedstocks used in the production of non-energy products also represent a significant amount of energy use in the

Figure 1. U.S. Energy Consumption, 1993

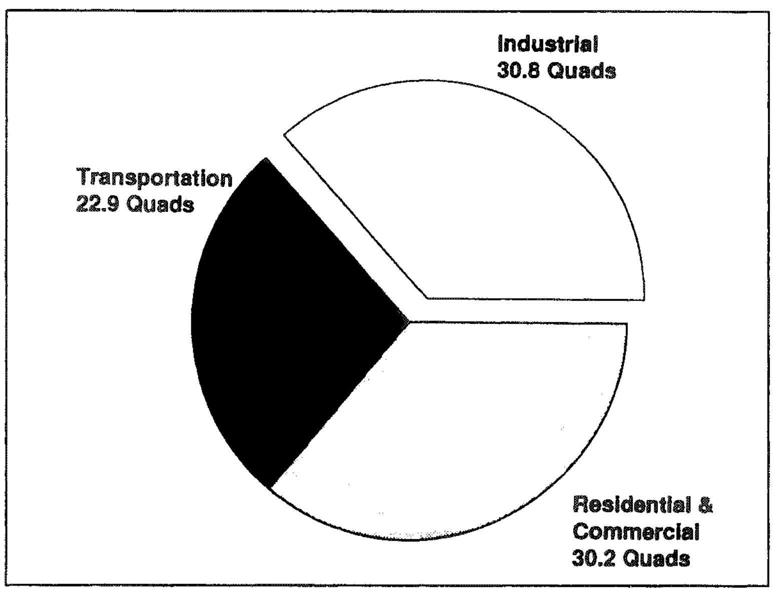
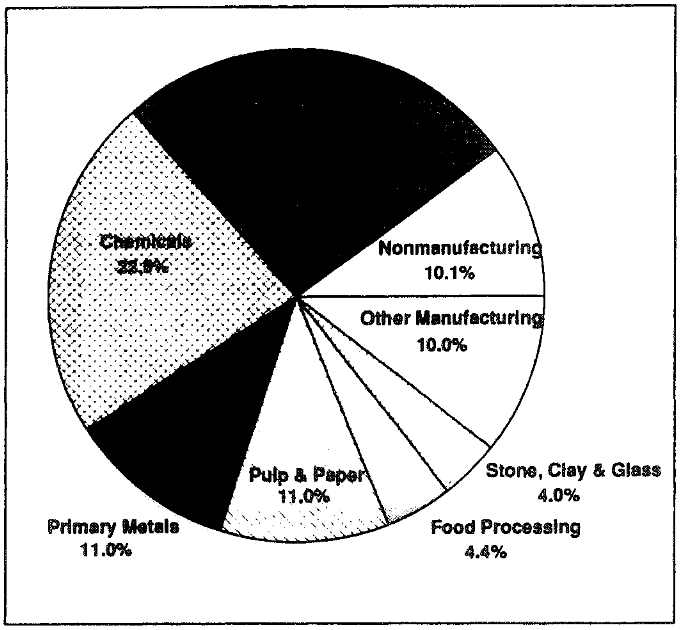


Figure 2. Energy Use in Basic Industries



basic industries (about 23 percent), as shown in Figure 3. Energy in the form of natural gas, petroleum and petroleum products is used extensively to produce a wide range of petrochemicals, plastics, and synthetic fibers in the chemical and petroleum industries. Coal is used in the steel industry to make coke, which provides the carbon needed to produce steel from iron ore.

While all the basic industries are energy-intensive, energy costs for heat and power as a percentage of production costs vary considerably (see Figure 4). For a few, such as producers of industrial gases, alkalies and chlorine, cement, and aluminum, energy's share of production costs exceeds 20 percent.

Because basic industries are so critical to our economy and quality of life, they represent important targets for productivity improvements through energy and resource efficiency, and have been the focus of many federal and state energy efficiency R&D programs. The development and application of more efficient technology could have a substantial impact on the energy consumed by these industries every year. To help formulate effective industrial energy policies and energy technology research programs, decision-makers need a sound understanding of industrial technology and its relative impacts on energy use.

Figure 3. Fuel and Feedstock Energy Use

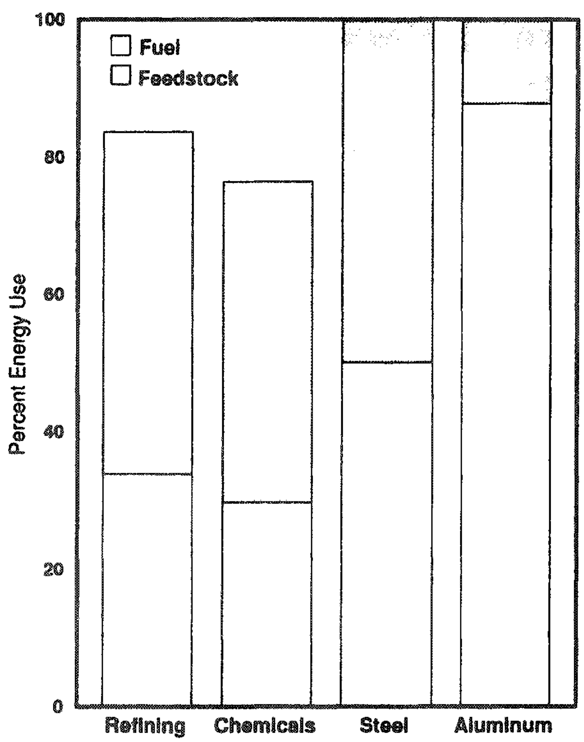
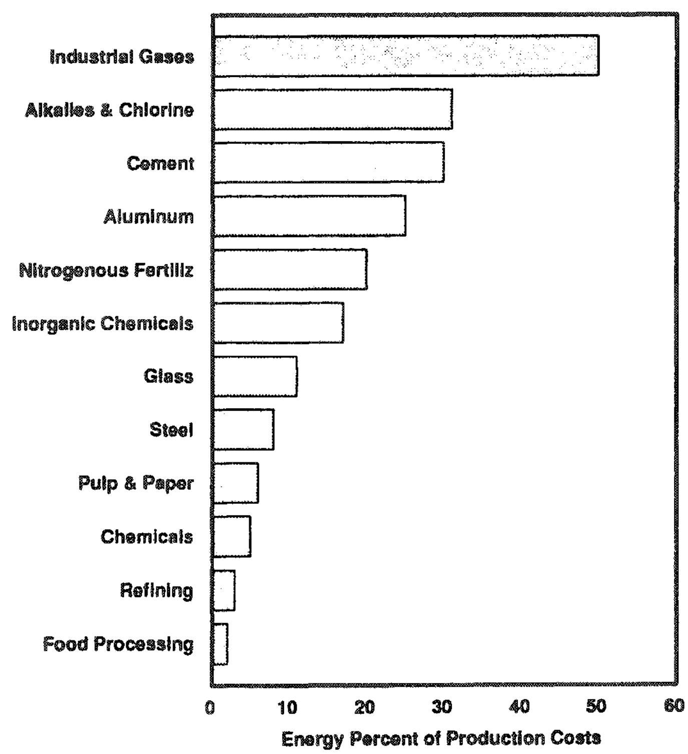


Figure 4. Energy's Share of Production Costs



INDUSTRIAL ENERGY PROFILES

While a number of studies have been conducted to examine industrial energy end-uses, few address the relative impacts of conventional and advanced technology on energy and resource efficiency. A few years ago a series of profiles was developed to help policy-makers and energy analysts evaluate the potential impacts of technological advance on individual industrial sectors, as well as some cross-cutting areas of energy consumption.[3] These profiles provide useful information on historical energy consumption and intensity, economic issues, production trends, process technologies, and opportunities for efficiency improvements through technology adoption. Industries and areas covered in the complete series include:

Basic Manufacturing Industries
Chemicals
Petroleum Refining
Food Processing
Pulp and Paper
Cement
Glass
Steel
Aluminum

Non-Manufacturing
Agriculture
Mining

Cross-Cutting Technology Areas
Electricity Use
Steam Generation and Cogeneration
Waste Utilization

In each profile, technology analysis provided a basis for projections of energy consumption over the next two decades using *historical, current practice, state-of-the-art, advanced technology,* and *business-as-usual* scenarios, as follows:

- *Historical* - based solely on a linear regression of historical energy use by fuel type.
- *Current Practice* - 100 percent use of currently-used technology.
- *State-of-the-Art* - 100 percent use of state-of-the-art technology. State-of-the-art technologies are the most efficient technologies available and demonstrated on a pilot or commercial scale.
- *Advanced Technology* - 100 percent use of energy-efficient advanced technology (conceptual or under development and have not yet been demonstrated at pilot scale, but with potential for industry acceptance).
- *Business-As-Usual* - Most likely mix of current, state-of-the-art, and advanced technology. Considers industry trends, i.e., rate of investment in new technology, level of R&D, and the structural background of the industry, and assumes the absence of a prolonged R&D effort to reduce energy use in industry.

All projections, except the historical projection, were based on an assumed production level and mix in 2010. Values in the intervening years of the projections were assumed to vary linearly between the first year of the projection and 2010. Sources for this information were developed through trade and professional associations, by personal contact with industry experts in the field, and through a review of the worldwide scientific literature.

While very useful for planning, forecasts of energy usage are uncertain, even where sophisticated models and studies are used as a basis. Changing economic trends, environmental regulations, energy availability and price, and any number of external events can alter the structure of industries over time and make predictions obsolete. Technology forecasting for the distant future has historically proven difficult, with revolutionary advances in technology having gone largely unforeseen by past generations. Except for the near-term, past performance is not a proven indicator of future performance. And expert judgements, which are used quite liberally in forecasting exercises, cannot possibly anticipate all the factors influencing future energy use. Accordingly, the limits of the projections provided in these profiles should be kept in mind when viewing the results.

Because each industry was assessed at the process level rather than by industry aggregate, these profiles provide a unique and complete perspective of industrial energy consumption. To date, these profiles have been widely used and referenced by energy analysts in both the public and private sector, and represent a unique source of information that is not replicated in any other publication. This paper provides a synopsis of data on seven of the basic industries included in the original profiles. Some of the industry-wide statistical data has been updated to reflect more current trends occurring since the profiles were originally published in 1990.

PETROLEUM REFINING

The petroleum refining industry is critical to the economic stability and energy security of the U.S., meeting energy demands for more than 190 million automobiles, trucks and busses as well as aircraft. In 1992 the refining industry shipped products valued at over $141 billion and employed more than 74,000 people. Although refining is the most energy-intensive industry in the U.S., energy costs for heat and power only account for about 3 percent of production costs, partly because the industry relies substantially on waste fuels (refinery gas) generated during the refining process. About 50 percent of energy consumption in refining is for non-fuel purposes (feedstock energy), and is included in materials rather than energy costs. Major processes include separations (atmospheric and vacuum distillation), conversion (catalytic, hydro, and thermal cracking), reforming, and hydrotreating. Of these, the most energy intensive are shown in Table 1, along with advanced technologies and their projected impact on energy use in 2010. Projected energy consumption based on the varying scenarios is shown in Figure 5.

Figure 5. Energy Profile of the Petroleum Refining Industry

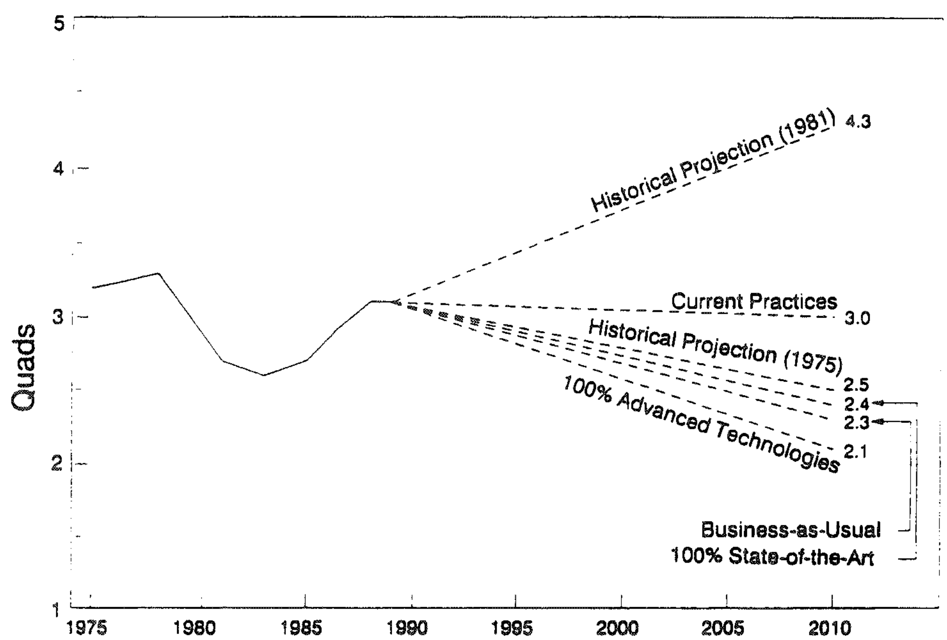


Table 1. Potential Energy Impacts of Advanced Technology on Major Refining Processes

Process	Advanced Technology	2010 Energy Use Current Practice (10^{12} Btu)	2010 Energy Use With Advanced Technology (10^{12} Btu)(% Savings)
Atmospheric Distillation	- Advanced vapor recompression - Advanced control strategies	584	495 (15%)
Vacuum Distillation	- Dry vacuum column operation - Fluid atmospheric resid (ART)	248	91 (63%)
Delayed Coking/ Visbreaking	- Fluid bed vacuum resid (ART) - Soaker visbreaking - HDH hydrocracking	101	54 (47%)
Fluid Catalytic Cracking	- Improved catalysts	264	184 (30%)
Alkylation	- Polymerization processes	231	115 (50%)

CHEMICALS

In 1992 the chemicals industry employed nearly 850,000 people in the U.S., and had annual shipments of over $305 billion, including $42 billion in exports. The chemical industry is exceptionally large and diverse, producing over 60,000 different products ranging from basic commodity chemicals to mass-marketed consumer goods such as drugs, detergents, and paints. Chemicals manufacture is the second largest industrial consumer of energy, but expends only about 5 percent of production costs on energy for heat and power. Nearly 50 percent of energy consumed in the chemicals industry is for non-fuel purposes (feedstock energy) and is included in material costs. Major energy-consuming processes include distillation, thermally-driven chemical reactions, electrolytic chemical conversion, evaporation, and refrigeration. Table 2 provides energy use data for selected high volume chemicals, along with the projected impact of advanced technologies on energy used to produce these chemicals in 2010. Projections of energy use based on the varying scenarios are shown in Figure 6.

Figure 6. Energy Profile of Ethylene Production

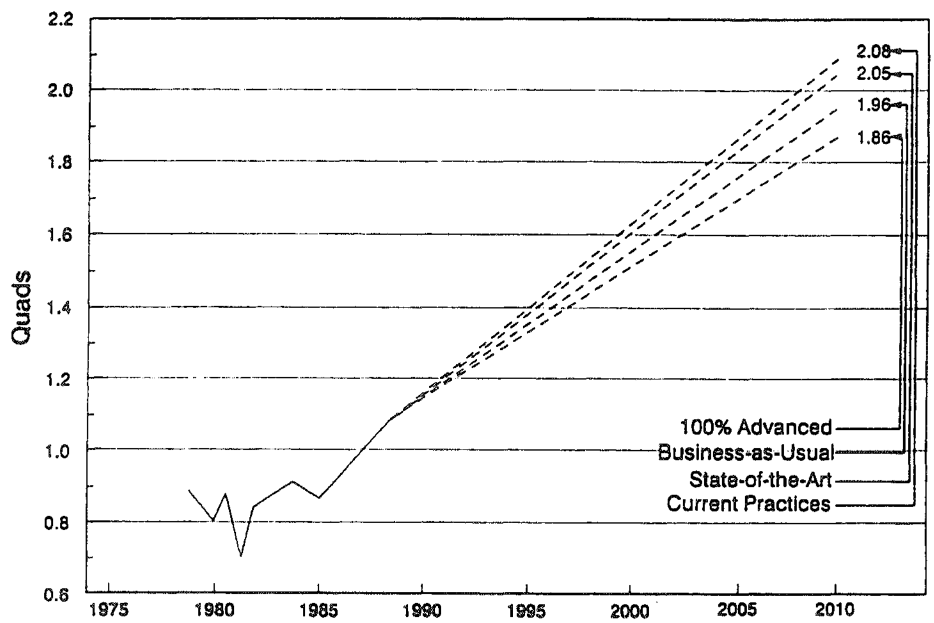


Table 2. Potential Energy Impacts of Advanced Technology on Major Chemical Processes

Chemical Product	2010 Energy Use Current Practice (10^3 Btu/ton)	2010 Energy Use With Advanced Technology (10^3 Btu/ton) (% Savings)
Nitrogen and Oxygen		
Separation	540	244 (55%)
Compression	409	409 (0%)
Liquefaction	1720	1720 (0%)
Electricity Losses	2517	1902 (24%)
Total	3728	2818 (24%)
Ethylene		
Feedstock Energy	53600	49000 (9%)
Process Energy	4600	3400 (26%)
Total	58200	52400 (10%)

PULP AND PAPER

The pulp and paper products industry is an integral part of the economy, producing a variety of industrial products and consumer goods. The industry employs over 600,000 people and produced about 86 million tons of paper and paperboard products in 1993, about 700 pounds for every man, woman, and child in the U.S. Pulp and paper is also a large consumer of energy (third in industry), and makes extensive use of renewable sources (pulping liquor, bark and wood) for fuel. Even so, the industry spent nearly $5.5 billion on purchased energy in 1991, or over 4% of the value of its shipments. Technical challenges facing the industry are centered on cost-effective use of recycled materials, meeting environmental regulations, and reducing energy costs. Major energy-consuming processes include pulping, bleaching, chemical recovery, and papermaking. The most energy-intensive of these are shown in Table 3, along with a comparison of advanced technologies and their projected impact on energy use in 2010. Projections of energy use based on the varying scenarios are shown in Figure 7.

Figure 7. Energy Profile of the Pulp and Paper Industry

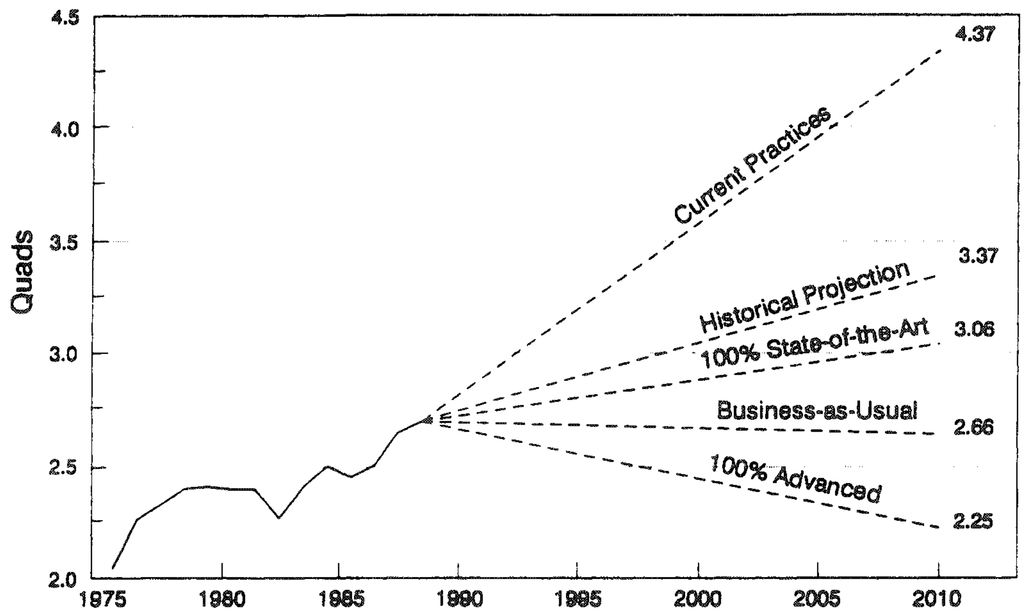


Table 3. Potential Energy Impacts of Advanced Technology on Major Pulp and Paper Processes

Process	Advanced Technology	2010 Energy Use Current Practice (10^{12} Btu)	2010 Energy Use With Advanced Technologies (10^{12} Btu)(% Savings)
Pulping	- Alcohol-based solvent pulping - Biological pulping - Non-sulfur chem/mech pulping	1135	701 (38%)
Bleaching	- Modifications/fewer stages	352	211 (40%)
Chemical Recovery	- Direct alkali recovery - Freeze concentration black liquor - Black liquor gasification	855	266 (69%)
Papermaking	- High-consistency forming - Wet pressing advances - Impulse drying	1609	690 (57%)

STEEL

Steel is the most basic and widely used metal in industry, and is vital to the economic and national security of the U.S. Although there are acceptable substitutes for steel in some uses, in the short term practical alternatives are few because of higher cost, inadequate performance, or insufficient availability. Moreover, the steel products industry is a $57 billion industry employing over 240,000 workers and shipping nearly 80 million tons of steel per year. The steel industry is the fourth largest energy consuming industry in the U.S. and uses significant quantities of feedstock energy. Energy used for heat and power accounts for about 8 percent of production costs. Over the last fifteen years the steel industry has undergone major restructuring and downsizing that has resulted in the shutdown of numerous steelmaking facilities and layoffs of tens of thousands of workers. Clean Air Act Amendments targeting coke ovens may force the shutdown of some steelmaking facilities, and the industry is actively developing and testing alternatives to conventional coke-based steel processes. Some of these processes could revolutionize current steelmaking by replacing traditional processes (e.g., direct steelmaking that eliminates the coke oven and blast furnace). Major energy-consuming processes include cokemaking, ironmaking, steelmaking, and heating and annealing. Table 4 lists a number of advanced technologies which have the potential to reduce energy consumption in major steelmaking processes and their projected impact on energy use in 2010. Projections of energy use based on the varying scenarios are shown in Figure 8.

Figure 8. Energy Profile of the Steel Industry

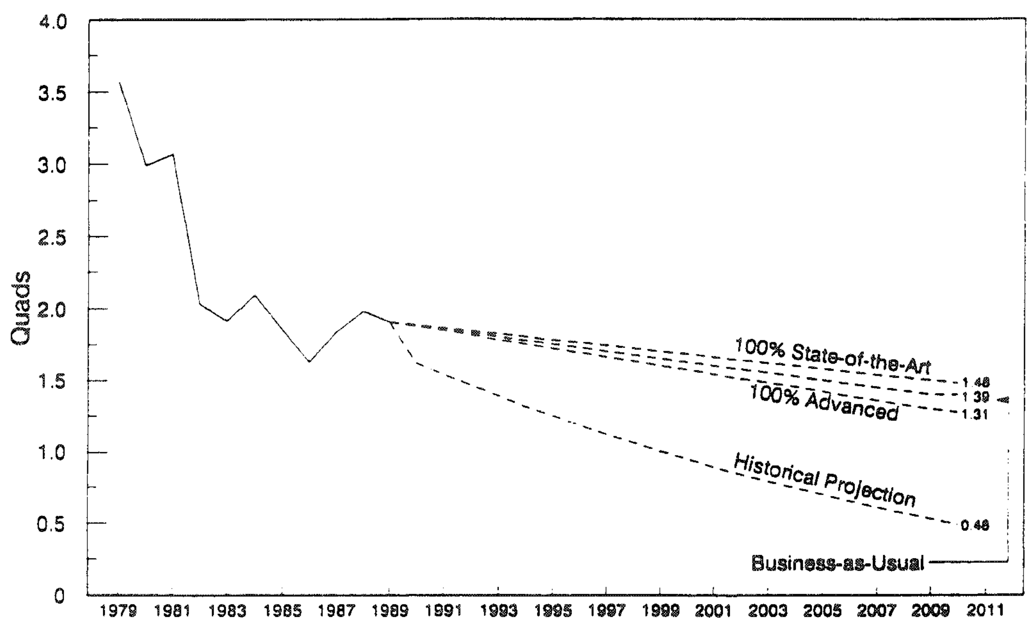


Table 4. Potential Energy Impacts of Advanced Technology on Major Steelmaking Processes

Process	Advanced Technology	2010 Energy Use Current Practice (10^{12} Btu)	2010 Energy Use With Advanced Technology (10^{12} Btu)(% Savings)
Cokemaking, Ironmaking, and Steelmaking	- Direct steelmaking (replaces coke oven and blast furnace) - Electric arc	1175	593 (50%)
Forming, Finishing, Heat Treating and Annealing	- Direct thin strip casting for hot and cold rolled sheet/strip and heavy plate products	285	155 (46%)

FOOD PROCESSING

Food processing includes producers of meat, dairy, fruit, vegetables, grains, fats, beverages, and a variety of other edibles. The food processing industries produced shipments totaling nearly $390 billion in 1991, and employed nearly 35,000 people. The industry is ranked fifth in industrial energy consumption, but expends only about 2 percent of production costs on energy. Natural gas and electricity meet most of the energy requirements in food processing, primarily for separations processes. About half of the energy used in food processing is for direct heating; the remaining is used to generate process steam and hot water. Among the most energy intensive food producers are wet corn millers, beet sugar processors, and malt beverage brewers. In general, processes which consume the most energy include concentration of food products from liquid streams, cooking, drying, and evaporation. Table 5 lists a number of advanced technologies which have the potential to reduce energy consumption in food processing, and their projected impacts on energy use in 2010. Projections of energy use based on the varying scenarios are shown in Figure 9.

Figure 9. Energy Profile of the Food Processing Industry

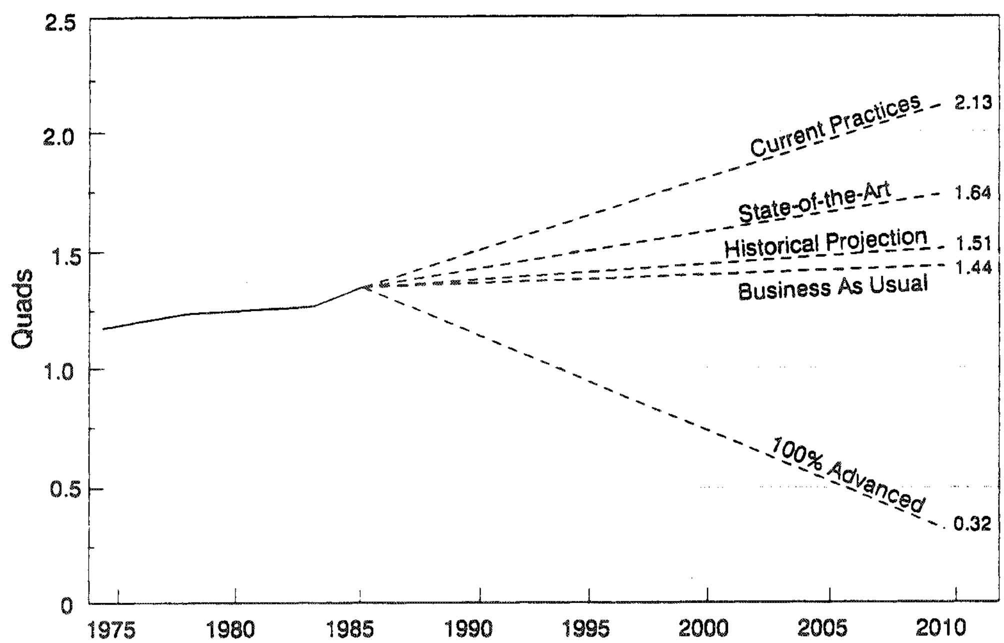


Table 5. Potential Energy Impacts of Advanced Technology on Food Processing

Process	Advanced Technology	2010 Energy Use Current Practice (10^{12} Btu)	2010 Energy Use With Advanced Technology (10^{12} Btu)(% Savings)
Pasteurization/ Sterilization	- Cold pasteurization - Electron beam sterilization and others	41	4 (90%)
Evaporation/ Concentration	- Supercritical extraction - Protein separation, and others	104	29 (72%)
Drying	- Vapor recompression - Supercritical extraction - Extractive drying, and others	91	5 (95%)
Chilling/Cooling Refrigeration	- Controlled atmosphere packaging, and others	45	3 (93%)

GLASS

Approximately 22 million tons of glass are melted each year in the United States to produce 21 million tons of glass products valued at $10.6 billion. Although the raw materials (sand, limestone, and soda ash) and refining/melting steps used for all types of glass-making are generally similar, downstream products and fabrication processes are very diverse (flat glass, glass containers, fiberglass, specialty glass). Of the total operating costs in glass production, about 11 percent is expended for energy. Current market drivers indicate that there is strong need to improve the melting and refining portions of the glass manufacturing process, which consume the most energy (54%) create the most environmental concerns (emissions, recycling, waste disposal), and which are the areas of glass making most technologically common to various segments of the industry. Table 6 describes a number of advanced technologies with the potential to reduce energy consumption in batch preparation and glass melting and refining, and their projected impacts on energy use in 2010. Projections of energy use based on the varying scenarios are shown in Figure 10.

Figure 10. Energy Profile of the Glass Industry

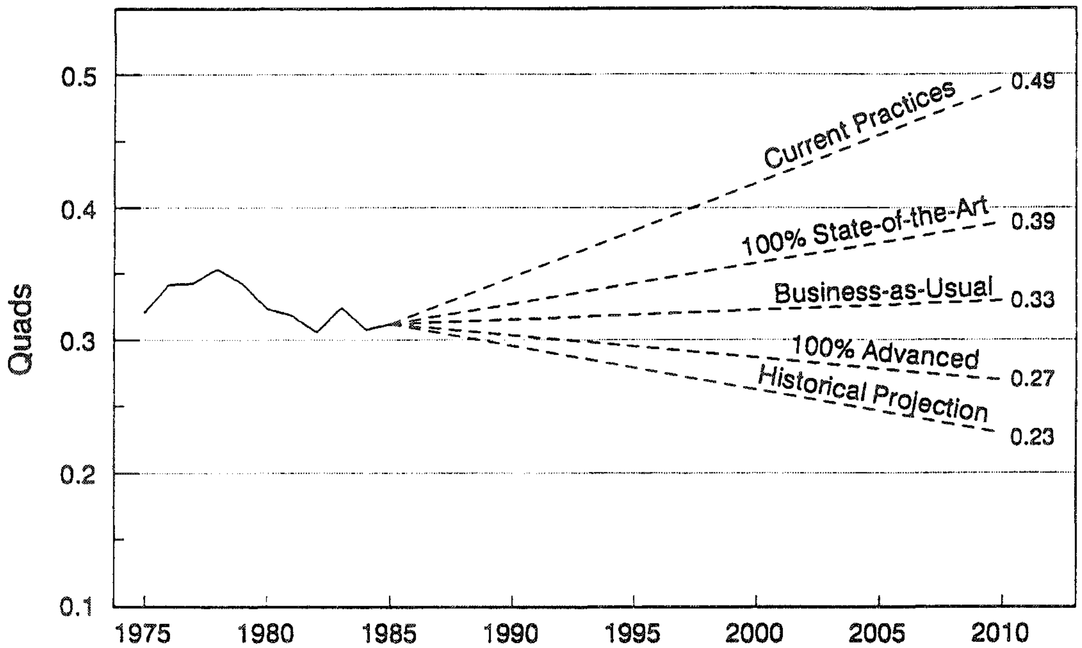


Table 6. Potential Energy Impacts of Advanced Technology on Major Glassmaking Processes

Process	Advanced Technology	2010 Energy Use Current Practice (10^{12} Btu)	2010 Energy Use With Advanced Technology (10^{12} Btu)(% Savings)
Batch Preparation	- Batch preheating - Cullet preheating - Raw material purification	21	19 (10%)
Melting and Refining	- Direct coal firing - Submerged burner combustion - Coal-fired hot gas generation - Advanced glass melter - Batch liquefaction - Ultrasonic bath agitation/refining - New furnace insulation - Pressure swing adsorption oxygen generator, and others	268	106 (60%)

ALUMINUM

The aluminum industry is an important element of the U.S. economy and provides raw materials for the manufacture of numerous consumer goods (e.g., automobiles, cans, structural materials, packaging). U.S. aluminum industry shipments in 1993 were 8.2 million metric tons, valued at about $31 billion, and the industry employs over 130,000 people. The U.S. has almost 23% of the world's capacity for primary aluminum production, but remains one of the higher cost producers at about 56 cents per pound. One reason is the cost of energy (aluminum production is the seventh largest industrial consumer of energy). Energy (mostly electricity consumed in Hall-Heroult electrolytic cells) accounts for one-fourth of production costs for primary aluminum. Rather than install greenfield aluminum smelters, domestic firms are increasingly investing in low cost aluminum capacity overseas in such countries as Venezuela, Brazil, Australia and Canada that have access to relatively low-cost electric power. Table 7 describes a number of advanced technologies that could have significant impact on energy consumption in traditional electrolytic aluminum production cells, and their projected impact on energy use in 2010. Projections of energy use based on the varying scenarios are shown in Figure 11.

Figure 11. Energy Profile of the Aluminum Industry

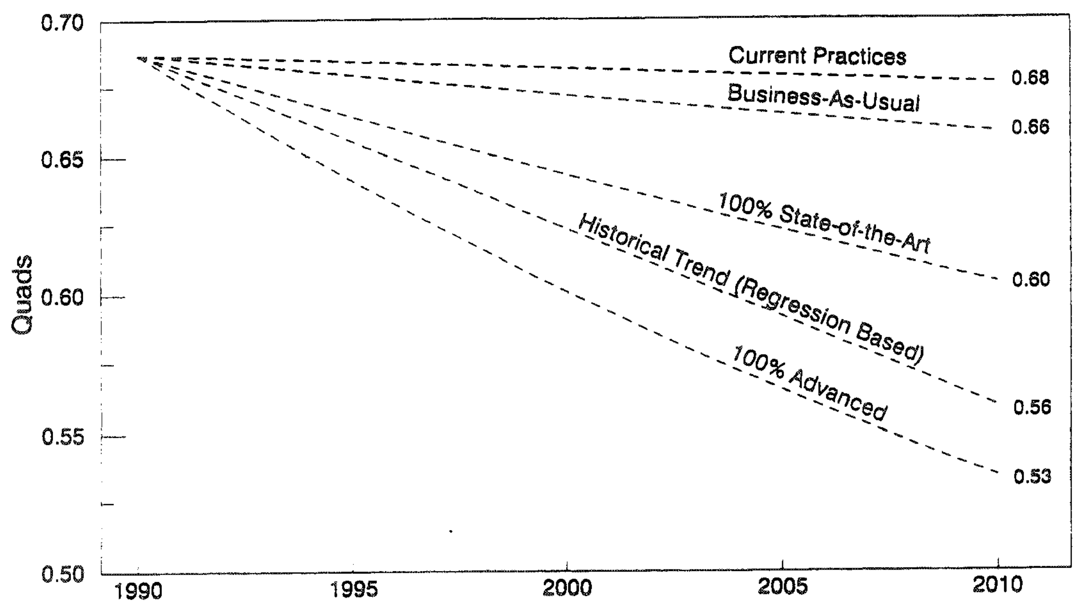


Table 7. Potential Energy Impacts of Advanced Technology on Major Aluminum Production Processes

Process	Advanced Technology	2010 Energy Use Current Practice (10^6 Btu/ton)	2010 Energy Use With Advanced Technology (10^6 Btu/ton)(% Savings)
Bauxite to Alumina with Bayer Process	- Carbothermic reduction	36	27 (25%)
Aluminum Smelting: Hall Heroult Process	- Inert anodes, cathodes, and sidewalls, reduce A-C distance - Carbothermic reduction - Aluminum chloride smelting - Reduction cell with bipolar electrode, and others	75	49 (35%)
Finishing	- Graphite cloth diaphragm	10	10 (0%)

CONCLUSION

From the energy profiles of these seven basic industries, it is obvious that the adoption of advanced, more efficient technology could make a significant impact on energy consumption and its associated costs. For some of these industries, reducing energy consumption by as little as 10 percent could make a competitive difference, particularly for those where energy costs are a significant percentage of production costs. Whether industry will actually invest int he development and subsequent adoption of more energy efficient advanced technology is uncertain. Energy R&D investment decisions are invariably the result of a balancing act that considers many factors, including changes in consumer demand, economic trends, the regulatory environment, competitiveness issues, and the availability and price of energy.

As we move toward the next century, U.S. industry will need to find dynamic ways to address the technological challenges of modern manufacturing in order to remain competitive. Clearly, to achieve the type of long-term economic growth that creates jobs and protects the environment will require new approaches to manufacturing. Modern production systems that use energy and materials more efficiently will edge out less competitive production practices and reduce environmental impacts in the process. Because they often address inefficiencies in the use of energy and materials, advanced manufacturing technologies will almost always lower production costs and increase long-term profitability, and will continue to be a viable option as industries strive to meet the economic and environmental challenges of the future.

Note

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