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EXECUTIVE SUMMARY

TECHNOLOGY PARTNERSHIPS
ENHANCING THE COMPETITIVENESS,
EFFICIENCY AND ENVIRONMENTAL QUALITY
OF AMERICAN INDUSTRY

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The Office of Industrial Technologies: Enhancing the Competitiveness, Efficiency, and Environmental Quality of American Industry through Technology Partnerships

Since the world oil embargo of the early 1970s, our Nation's energy policy has emphasized improving both energy supply and end-use efficiency. Over the past 20 years, the private and public sectors each have made valuable contributions to energy efficiency and environmental improvement.

An important component of the Federal Government's effort to stimulate improved industrial energy efficiency is the Department of Energy's (DOE's) Office of Industrial Technologies (OIT). OIT engages private sector firms in cost-shared research, development, and deployment partnerships that address emerging and strategic technology needs identified by prominent panels of industry experts and executives.

This document briefly describes OIT's program. It profiles the energy, economic, and environmental characteristics of OIT's principal customers—the materials and process industries—that consume nearly 80% of all energy used by industry in the United States. OIT-supported research, development, and demonstration (RD&D) activities relating to these industries are described as well as OIT's crosscutting technology programs that target the needs of multiple U.S. industries. Quantitative estimates of the potential benefits (or metrics) to U.S. industry of many current OIT-supported technologies are also discussed.

This Executive Summary highlights a more detailed report that contains an in-depth description of the OIT RD&D program, its context, and potential future benefits. The full report provides most of the information we believe our customers want to know about our program. It is an out-

growth of OIT's evolution to a Total Quality Management (TQM) organization—one that strives to continuously improve the quality of its products, services, and the satisfaction of its customers. We urge our readers to review the full report for more information on any subject discussed in this brief summary.

The Executive Summary and the full report complement another document titled "Summary of Program Impacts." This document provides descriptions of OIT-supported technologies that have been successfully commercialized and analyzes the impacts these technologies have already had on industry. Taken together, the two reports provide an accounting of the past, current, and potential future energy, economic, and environmental benefits of the OIT program to industry and the Nation.

In keeping with our TQM philosophy, we invite your comments or questions about either of the documents or any other aspect of the OIT program; contact points are listed on the inside back cover of each of these reports. We hope these reports will stimulate dialogue with our customers about their needs, the extent to which our products and services meet those needs, and how we can improve our products and services in the future.

OIT Mission

The mission of OIT is to develop and deploy—through cost-shared partnerships with industry, Government, and nongovernmental organizations—advanced energy efficiency, improved productivity, renewable energy, and pollution prevention technologies.

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OIT: The Strategic Context

WHY FEDERAL SUPPORT OF ENERGY EFFICIENCY RESEARCH AND DEVELOPMENT IS NEEDED

There is a gap emerging in the funding of medium- and long-term research and development (R&D) that threatens to limit the future stock of innovative technology U.S. industries will need to remain competitive and environmentally sound. Driven by competitive pressures to downsize, streamline, move technology closer to the customer, reduce costs, and improve quality, U.S. firms increasingly are devoting their scarce resources to short-term product and process development.

Private sector U.S. firms often are not inclined to undertake the typically costly, high-risk, long-term R&D required to develop the highly efficient, clean, breakthrough technologies that will be needed to compete successfully in tomorrow's global economy. Many promising fundamental improvements in the energy-, waste-, and capital-intensive industries that are OIT's principal customers are simply too expensive and too risky for individual private firms to pursue by themselves.

OIT COST-SHARING LOWERS THE RISK AND COST OF BREAKTHROUGH TECHNOLOGIES

Such trends and developments mean that prospects for a safe, secure, and affordable energy future in the 21st century cannot be addressed by the private sector alone. OIT recognizes that while there are appropriate limits to government support of new technologies, organizations like OIT have an essential role to play in helping to keep U.S. basic industries technologically competitive.

In the absence of private sector investment, OIT cost-sharing can lower the risk and cost of technology development to a level more acceptable to private sector partners. OIT targets technologies with the potential for large national benefit but that are too risky for individual firms to pursue by themselves. OIT acts as a catalyst in drawing together many firms with national laboratories and other interested parties to pool risk, investment, and know-how in promising technologies that are too costly and high-risk for individual firms to develop on their own.

OIT partnerships facilitate success in the type of high-payoff R&D that offers the most potential for stimulating economic growth and creating high-wage jobs. Such cost-shared partnerships also help assure the taxpayer that Federal funding is supporting R&D in areas that are of serious interest to industry.

OIT'S PROGRAMS SUPPORT SEVERAL OF DOE'S STRATEGIC GOALS

OIT is part of DOE's Office of Energy Efficiency and Renewable Energy (EE). EE has the overall mission of leading the nation to a stronger economy, a cleaner environment, and a more secure future through developing and deploying sustainable demand-side and renewable energy technologies.

OIT's programs are in direct support of several key goals of DOE's strategic plan. OIT supports DOE's industrial competitiveness goals: (1) creating partnerships with the private sector to maintain and leverage R&D resources (2) accelerating industry's use of available and emerging competitive

technologies, processes, and practices and (3) shifting from industrial waste management to resource efficiency and pollution prevention.

OIT's programs also support DOE energy resource goals: (1) ensuring reliable energy services with reduced vulnerability to energy price and supply volatility and (2) reducing adverse environmental impacts associated with energy production, delivery, and use.

Finally, OIT supports DOE's strategic goals in science and technology. OIT programs help provide the science and technology core competencies that enable DOE's other businesses to succeed in their missions. These programs also add value to the U.S. economy through the application of new and improved technologies.

THE INDUSTRIES OF THE FUTURE PROCESS

A close-working relationship with industry, professional organizations, and other groups has been a hallmark of OIT programs since they were established in the 1970s. These cooperative efforts help to ensure that new technologies are relevant to industry's needs and encourage industry acceptance.

To be certain that its program continues to be responsive to the long-term needs of its customers, OIT launched an important initiative known as Industries of the Future. This initiative strengthens collaboration between industry and government and promotes leveraging of scarce R&D resources to the maximum extent allowable.

Industries of the Future is a process in which industry participants—facilitated by OIT—create a vision that reflects the diverse technological, economic, and environmental drivers that are shaping the future of their industry (Figure 1). The vision is developed by industry for industry. It provides a framework for shaping major advancements in technologies according to their potential for improving industrial efficiency, energy and materials use, and environmental protection.

Industries of the Future facilitates integrated planning and implementation by all participants, fosters cooperative planning among different organizations in DOE and other government agencies, and focuses RD&D on technologies that are responsive to the unique challenges each industry faces.

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In keeping with its energy efficiency mission, OIT's Industries of the Future initiative concentrates on the most energy-intensive industries because those industries possess the greatest opportunities for improved energy efficiency. This includes the chemical, petroleum refining, forest and paper products, steel, aluminum, metal foundry, and glass industries.

OIT PRODUCTS AND SERVICES

OIT accomplishes its mission through a variety of technology research, development, demonstration, and deployment programs, plus partnership and teaming arrangements. OIT concentrates on supporting both efficient and cleaner industry-specific technologies and processes, as well as innovative crosscutting technologies and processes used in many manufacturing industries.

OIT carries out a significant part of its mission by offering financial assistance to qualified organizations in the public and private sectors in exchange for products and services that meet OIT's program objectives. Two of the most important mechanisms available for industrial participation in OIT programs are: (1) cost-shared financial assistance awards and cooperative agreements that are legal instruments negotiated between industry and Government and (2) cooperative research and development agreements (CRADAs) between Government laboratories

Figure 1
Industries of the Future Process

and nonfederal parties in which both participants provide personnel, services, facilities, or equipment to conduct specified R&D.

To implement these mechanisms, OIT uses competitive public solicitations. Proposals submitted in response to a competitive solicitation are evaluated, with awards going to the most highly qualified offeror(s). Solicitations are also issued by OIT through the Small Business Innovation Research program.

OIT also accepts and funds a limited number of unsolicited R&D proposals. To be considered, unsolicited proposals must demonstrate a unique and innovative idea, method, approach, or capability. They must also address a topic not already covered by a recent, current, or planned solicitation.

In addition to cofunding RD&D, OIT has long been committed to promoting technology deployment through fact sheets, brochures, and case studies about new programs and specific DOE-sponsored research. OIT also works closely with industry trade associations and technical societies, sponsors technical workshops, and cooperates with state and local governments. In addition, OIT sponsored the first National Symposium and Exposition on Industrial Energy Efficiency to promote more productive interactions among the vast community of industrial technology developers, suppliers, and users.

OIT CAN POINT TO DOZENS OF COMMERCIAL SUCCESSES

National laboratory surveys have helped document the beneficial impacts of OIT-supported technologies. At the end of 1994, more than 65 OIT technologies had been commercialized, contributing to cumulative energy savings of about 614 trillion Btu. At today's prices, this translates into total energy cost savings of more than \$2.4 billion—more than double the cumulative \$1.1 billion invested since 1978 to achieve these savings. These and other documented benefits of the OIT program are described more fully in the "Summary of Program Impacts."

Photo courtesy of Ankers Photography

Department of Energy Secretary Hazel O'Leary, Senator Chuck Robb of Virginia, and James River Corporation CEO Robert Williams participated in the signing of Agenda 2020 in November 1994.

Profiles of OIT's Principal Customers: The Materials and Process Industries

U.S. INDUSTRY USES MORE THAN ONE-THIRD OF ALL ENERGY AT A COST OF ABOUT \$100 BILLION/YEAR

American industry relies on energy to generate heat and steam for industrial processes; power motors and machines; light, heat, and cool factories and offices; and fuel vehicles. Oil and natural gas are also feedstocks for manufacturing plastics and other materials.

U.S. industry consumes about 23 quadrillion Btu (quads) of energy each year (Figure 2). If electric power generation losses are included, this equals about 37% of total U.S. energy use.

Industry's huge appetite for energy is an expense that costs about \$100 billion/year. Although this is a huge sum, overall it amounts to only about 3% of industry's total cost of doing business (Figure 3).

Figure 2
Energy Consumption by Major Industry, 1991

Sources: EIA, *Monthly Energy Review*, October 1993

DOC December 1992

Source: 1991 Annual Survey of Manufacturers: Statistics for Industry Groups and Industries;

Notes: Costs of purchased energy include electricity and fuels consumed for heat, power, and electricity generation, or maintenance; contract work; bought and resold products; and labor (including wages, nonwage benefits, and social security and other legally required payments).

Figure 3
Energy Purchases and Their Share of Production Costs by Industry, 1991

However, the cost and significance of energy to industry varies a great deal from one industry to another. An important but not well understood fact about industrial energy use is that a handful of just six major industries (petroleum refining, food processing, metals, paper, glass/ceramics, and chemical) account for about 78% of all industrial energy use and 87% of all energy used in U.S. manufacturing.

ENERGY IS AN IMPORTANT COST AND COMPETITIVENESS FACTOR

Because of their high energy use, materials and process industries spend more

on energy than other industries. Generally, energy costs amount to at least 10% of the total costs of these basic industries. Improving their energy efficiency remains important to these industries because it can result in both lower energy use and reduced costs—despite today's low energy prices. At the same time, efficiency gains improve the productivity and competitiveness of these industries. Despite efficiency improvements, DOE forecasts that total industrial energy use will grow by 22% between 1993 and 2010—to 31.2 quads.

At current usage rates and prices, the materials and process industries would consume 24 quads of energy and their total energy bill would be \$100 billion by 2010.

For these reasons, the materials and process industries are the principal focus of OIT's RD&D program and its Industries of the Future initiative. OIT targets the materials and process industries because they offer the best opportunities to improve energy efficiency and reduce energy costs.

The Materials and Process Industries Account for 8% of Gross Domestic Product

The materials and process industries are not just energy-intensive; they are also a huge and critical component of the overall economy. Because of their role as essential suppliers of materials, fuel, and similar items to the industrial infrastructure as a whole, the health and competitiveness of these industries are tightly intertwined with the many manufacturing industries they support.

In 1992, the materials and process industries shipped nearly \$1.2 trillion worth of products, or 40% of all manufacturing shipments. Subtracting their costs, these industries collectively add \$400 million/year to the economy directly, equal to about 8% of U.S. Gross Domestic Product (GDP).

Consistent with their high level of shipments, the materials and process industries are also a major source of well-paying jobs to the economy. They employ 4.2 million people—23% of the total manufacturing workforce, and 5% of the Nation's total, non-farm, private sector employment.

These industries are also among the highest-paying in the economy. On average, their wages exceed those of manufacturing overall by 12% and are 22% higher than those paid to service industry employees (Figure 4).

Due to the sheer physical size and throughput of the materials and process industries, they are also highly

capital intensive. Of all capital expenditures for manufacturing in 1992, these industries accounted for 47%.

Their high capital intensity, in turn, has an important multiplier effect in creating jobs and wealth outside these industries. Each job in the materials and process industries is estimated to support four jobs in

supplier, equipment, repair, finance, engineering, sales, and even Government occupations.

Industrial Competitiveness Is Crucial

Almost 20% of U.S. merchandise trade comes from the materials and process industries including exports, which totaled \$101 billion in 1993. Due in

Figure 4

Wages in the Materials and Process Industries Compared to Other Industries

Source: 1992 Census of Manufacturers; Statistical Abstract of the United States 1993 (Table #662)

Figure 5

R&D Expenditures in the Materials and Process Industries

*Estimated

Sources: Research and Development in Industry, 1992, National Science Foundation, 1992 Census of Manufacturers, Bureau of the Census

large part to the chemical industry, these industries had a trade surplus of about \$8 billion in 1993—compared to an overall U.S. merchandise trade deficit of \$136 billion.

Because of the fungible, commodity nature of most of their products, virtually all the materials and process industries face strong international competition. Continuous improvement and innovation are more critical than ever if these industries are to succeed in the competitive global economy.

Given their scale economy nature and the relative maturity of many of their markets, these industries tend to have conservative innovation strategies. With the exception of the chemical industry, R&D expenditures for the materials and process industries are substantially below the manufacturing average (Figure 5).

Furthermore, because of the need to cut costs and achieve quick paybacks, there is an emerging gap in funding mid- and long-range R&D in these industries—the very type of innovative technology on which future competitiveness is most likely to be based.

MATERIALS AND PROCESS INDUSTRIES YIELD 95% OF MANUFACTURING WASTE

The materials and process industries are not only energy-intensive and economically significant, they also generate huge quantities of waste and pollution.

Despite conflicting definitions and scarcity of reliable data, the best available information suggests that on a volume basis, five materials and process industries—chemicals, paper, metals, petroleum refining, and glass/ceramics—account for 95% of all manufacturing wastes, including:

- ❑ Air emissions
- ❑ Solid wastes
- ❑ Sludges
- ❑ Huge amounts of wastewater.

Figure 6
Pollution Abatement Costs and Expenditures, 1973–1992

Source: Pollution Abatement Costs and Expenditures, 1992, DOC March 1994

These industries' waste generation occurs because their function in the economy is to convert raw materials supplied by the extractive industries into ingredients useful for fabrication and assembly in the automotive, electronics, aerospace, construction, and similar industries. The critical role of materials and process industries is to separate useful materials from useless waste—metals from ore, fiber from lignin, wheat from shaft, and so on.

By their very nature, the materials and process industries are waste- and pollution-intensive. They account for 84% of all toxic waste and 95% of all hazardous waste generated in manufacturing. They also generate more than 95% of manufacturing air pollution.

The high proportion of manufacturing waste and pollution generated by these industries is reflected in their above average pollution control costs. About 75% of all pollution control costs in manufacturing are borne by the materials and process industries (Figure 6).

On average, manufacturers spend about 0.8% of sales for pollution control, but the materials and process industries spend at least twice this

amount. Also, pollution control accounts for a much greater share of capital expenditures in these industries than it does in others. This is a critical issue for industries struggling to be globally competitive.

OIT-supported RD&D efforts attempt to help industry reduce these costly, nonproductive investments while simultaneously benefiting our Nation's environment. OIT technologies target pollution prevention and waste reduction rather than end-of-pipe clean up. OIT's program enhances not only industry's energy efficiency but also its materials efficiency and environmental profile.

OIT'S Industry-Specific Technology Programs for the Materials and Process Industries

The Chemical Industry

The chemical industry is sometimes called the keystone industry because its products improve the productivity and quality of goods manufactured by so many other industries.

It is the largest U.S. exporting industry: in 1993, exports were \$42.7 billion. The chemical industry must retain its strong competitive stance or risk aggravating the chronic U.S. trade deficit.

The industry's success has been based on its traditionally large R&D funding and strong propensity to innovate. More than 80,000 scientists, engineers, and technicians are employed in chemical-related R&D. Chemical companies spend more than \$16 billion on R&D—about 5.5% of its sales vs. a 3% average for all of manufacturing.

But the industry's R&D focus is shifting toward new product development and away from more basic breakthroughs. In the face of being downsized or eliminated, central research labs are focusing on near-term goals.

Chemical Industry Profile*

Value of Shipments	\$306 billion
Total Employment	850,000 jobs
Capital Expenditures	\$16.5 billion
Net Trade Balance	\$15.5 billion
Energy Consumption	5.05 quadrillion Btu
Waste Generation	1.84 billion tons
Average Hourly Earnings	\$15.25

*Data for latest year available

Figure 7

Sources and Uses of Energy in the Chemical Industry, 1991 (in Btu quads)

Source: EIA

ENERGY

The chemical industry uses about 5.1 quads of energy annually, with 53% used for fuel and power, and 47% for feedstocks. Four of the industry's segments—inorganics, organics, plastics, and fertilizers—use almost 90% of the industry's fuel and electricity (Figure 7).

Energy efficiency in the chemical industry has improved 51% since 1974. Energy used for chemical feedstocks has grown from 39% in 1970 to 48% today, mainly due to growth in the use of plastics.

ENVIRONMENT

The chemical industry produces more than 2 billion tons of waste/year—mainly wastewater. It accounts for about 90% of all industrial hazardous waste and more than 40% of all industrial toxic waste. The industry's major challenge is to reduce various air pollutants, especially volatile organic compounds (VOCs) and sulfur and nitrogen oxides.

The 1990 Clean Air Act Amendments set standards for industrial sources of 148 chemical pollutants that must be

met by 2003. Such regulations inhibit development of new materials and other products that underlie the industry's growth and competitiveness.

SELECTED OIT CHEMICAL INDUSTRY TECHNOLOGIES

OIT's chemical industry program is investigating novel methods of producing chemicals efficiently and cleanly. The alternative feedstocks program is developing economically feasible, environmentally sound processes for producing chemicals from renewable resources, thus reducing the amount of chemicals produced from petroleum-based feedstocks.

R&D efforts are under way in membrane technology for chemical processes that have significantly lower energy needs than conventional ones, less environmental impact, and lower costs. Researchers are studying bioprocesses such as using genetically engineered microorganisms and enzymes that act as biocatalysts to produce various commodity chemicals.

The Petroleum Refining Industry

The petroleum refining industry produces transportation fuels and raw materials for industry. It supplies 97% of the energy to fuel more than 190 million automobiles and other vehicles, plus all aircraft.

The number of operating refineries has declined 34% in several decades, from 285 in the 1960s to 187 in 1993. No grassroots refineries have been built in the U.S. for over a decade. Among the 10 largest refinery capacity owners in the U.S., four are foreign companies. Overall, imports of foreign crude and refined oil products supply almost half the U.S. market (Figure 8).

ENERGY

Petroleum refining consumes about 6 quads of energy, more than any other U.S. industry. Over half of the industry's energy comes from refinery gas produced in house. Energy efficiency has decreased 9% since 1985 largely because of lower quality crudes.

ENVIRONMENT

Environmental regulations and public opposition to expansion are an ever-increasing burden on U.S. refiners. Clean Air Act Amendments require some refineries to undertake process modifications to reduce SO_x and NO_x emissions.

Petroleum Refining Industry Profile*

Value of Shipments	\$136 billion
Total Employment	75,000 jobs
Capital Expenditures	\$6.7 billion
Net Trade Balance	-\$3.7 billion
Energy Consumption	5.97 quads
Waste Generation	180 million tons
Average Hourly Earnings	\$17.67

*Data for latest year available

Figure 8
Operable U.S. Refinery Capacity, Crude Oil Inputs, and Petroleum Demand, 1970–1992

Source: EIA

The National Petroleum Council estimates that refineries will spend \$150 billion by 2010 to comply with these regulations. Certain refineries may have to close rather than upgrade their facilities to meet the new standards. Sixty-five small refineries are especially threatened. Unless cost-effective solutions are found, the competitiveness of U.S. refineries will be severely impaired.

SELECTED OIT REFINING INDUSTRY TECHNOLOGIES

OIT is sponsoring R&D on cost-effective, energy-efficient technologies to help U.S. petroleum refineries stay competitive while complying with strict environmental regulations. Researchers are involved in several strategies that can lead to improved refinery technologies:

- ❑ Studying refinery emissions to develop a base of understanding
- ❑ Developing advanced technologies to produce cleaner fuels for the future
- ❑ Developing new ways of using refinery wastes.

Photo courtesy of Stavia Grand

The structure and configuration of U.S. refineries have changed during the past 25 years.

The Pulp and Paper Industry

The pulp and paper industry is the backbone of the information economy, and U.S. per capita paper use leads the world. Capital investment is the highest of all manufacturing industries, so paper firms have an important multiplier effect in creating jobs and wealth outside their industry. The U.S. pulp and paper industry is a strong global competitor compared to other G-7 nations, but competition from developing countries with large forest resources (e.g., Brazil) is growing.

ENERGY

The paper industry uses about 2.5 quads of energy/year or about 31 million Btu/ton of paper. Because it relies heavily on black liquor, bark, and wood to meet its energy needs, it uses two-thirds of all renewable fuels consumed by U.S. industry. It also accounts for 40% of all power cogenerated by U.S. manufacturing. Still, it spends \$5.5 billion on energy—4.3% of its value of shipments.

ENVIRONMENT

Water pollution control is the major environmental issue facing the pulp and paper industry. In 1991, it generated about 2.25 billion tons of waste, mostly as non-hazardous wastewater and sludges. The industry's chlorine bleaching process creates waste streams that can contain toxic materials, including dioxins.

*Pulp and Paper Industry Profile**

Volume of Products	85 million tons
Value of Shipments	\$133 billion
Total Employment	626,000 jobs
Capital Expenditures	\$7.8 billion
Net Trade Balance	\$-1.4 billion
Energy Consumption	2.5 quadrillion Btu
Waste Generation	2.25 billion tons
Average Hourly Earnings	\$13.80

*Data for latest year available

Photo courtesy of Donald Meadow, TAPPI Journal

Logs are cut to size on the truck at a plant that produces corrugating medium and linerboard.

Annual air emissions from paper production include 800,000 tons of VOCs, 340,000 tons of sulfur, and 150,000 tons of other hazardous air pollutants. Pollution abatement expenditures in 1991 amounted to \$1.6 billion in operating costs and \$1.2 billion in capital investment.

Recycled paper provides about 31% of the fiber used at paper mills.

SELECTED OIT PAPER INDUSTRY TECHNOLOGIES

OIT-supported paper industry technologies focus heavily on pulping chemical recovery processes, which are complex and not well-understood. OIT sponsors research on the properties of black liquor—the combination of dissolved wood waste and used pulping chemicals. The researchers' goal is to develop computer models to improve the efficiency of the chemical recovery process, thereby reducing emissions and improving productivity. In another effort, researchers are incorporating the chemical reactions that take place during the recovery process into a computer model to help them design optimal process conditions.

Researchers are also studying innovative ways to recover the valuable pulping chemicals that are more energy-efficient, less polluting, cheaper, and safer than the current processes. One method, gasification, yields a usable fuel and recovers the chemicals.

Finally, OIT is developing a new technology known as impulse drying. This technology reduces the moisture content of paperboard during pressing—the last step before drying. It lowers energy use in the drying section and allows the paper machine to run faster, thus increasing productivity.

The Steel Industry

The steel industry is divided into two major segments: (1) large, integrated producers that smelt iron ores to liquid iron in blast furnaces and refine the iron in basic oxygen furnaces, and (2) nonintegrated producers that rely primarily on scrap for their raw materials.

The steel industry has undergone drastic restructuring over the last decade by:

- ❑ Investing heavily in continuous casting
- ❑ Adopting new management styles
- ❑ Closing many outmoded plants
- ❑ Improving quality
- ❑ Boosting productivity at a 7% annual rate since 1984.

Such changes helped 1993 industry shipments reach their highest level since 1981 while import market penetration was at its lowest since 1980 (Figure 9). Also, the industry returned to profitability during 1993-94 after sustaining a cumulative deficit of \$3.5 billion between 1989-92.

ENERGY

Annual energy use in the steel industry is about 1.7 quads, or about 21 million Btu/ton of finished steel. The industry spent \$4.8 billion on purchased energy in 1991—8.7% of its

Steel Industry Profile*

Volume of Products (1993)	82 million tons
Value of Shipments	\$57 billion
Total Employment	236,000 jobs
Capital Expenditures	\$2.6 billion
Net Trade Balance	-\$4.5 billion
Energy Consumption	1.7 quads
Waste Generation	8 million tons of dust and sludge
Average Hourly Earnings	\$17.52

*Data for latest year available

Figure 9
Trends in U.S. Steelmaking

value of shipments. Coal supplies about 50% of the industry's energy, and natural gas supplies about 25%. Electricity is the dominant energy source among scrap-based minimills.

ENVIRONMENT

The steel industry's air pollutants include carbon monoxide, nitrogen oxides, sulfur dioxide and particulates. Steel firms also generate about 8 million tons of dust and sludge waste each year. Coke oven emissions are targeted for strict control under 1990 Clean Air Act Amendments. Coke output has already declined sharply from 60 million tons in the early 1970s to 24 million tons in 1992.

Steel industry capital expenditures for pollution control were about \$287 million in 1992, while operating costs for pollution control add an average of \$14/ton of steel shipped—or \$1 billion total in 1991.

About 60% of all steel produced is from recycled scrap.

SELECTED OIT STEEL INDUSTRY TECHNOLOGIES

A major effort in OIT's steel program has been the development of direct steelmaking, a revolutionary technology that eliminates cokemaking

while reducing energy, operating, and capital costs and improving productivity. OIT is also developing advanced methods to measure steel properties from melting through forming. The ability to accurately measure temperature, strength, and other variables will help optimize the steelmaking process.

Several OIT projects focus on steel wastes. An electrochemical dezincing process would enable the constituents of galvanized steel scrap—high quality steel and the zinc used to coat it—to be recycled. OIT has also initiated a project to recycle steel mill dust and sludge.

The Aluminum Industry

Between 1987 and 1992, about 1.1 millions tons of high-cost U.S. aluminum capacity (nearly 25% of U.S. total) were closed. Still, the U.S. remains a high-cost aluminum producer compared to countries such as Russia and Canada (Figure 10).

Lower power costs in competing countries make it unlikely that greenfield smelters will be built in the U.S. Domestic aluminum firms are more likely to retrofit existing plants with incrementally improved technologies. Increased investment in U.S. aluminum fabrication and recycling facilities is also expected.

Energy savings and waste disposal concerns boosted aluminum recycling from 0.4 million tons in 1960 to 2.8 million tons in 1992.

ENERGY

Aluminum smelting is one of the most energy-intensive manufacturing processes. Smelting operations, which mainly use electricity, account for 70% of energy use for primary aluminum. The annual primary energy consumption is about one quad. It takes about 7 kWh to produce one pound of aluminum and 180 million Btu/ton of aluminum. Recycled aluminum requires only about 5% of the energy needed to make primary metal.

*Aluminum Industry Profile**

Volume of Products	8.2 million metric tons
Value of Shipments	\$21 billion
Total Employment	134,000 jobs
Capital Expenditures	\$0.8 billion
Net Trade Balance	-\$0.3 billion
Energy Consumption	1.0 quad (including electricity losses and alumina)
Waste Generation	130,000 tons of potliner and red mud
Average Hourly Earnings	\$15.14

*Data for latest year available

Figure 10

Aluminum Smelting Capacity and Recycling in U.S.

Source: U.S. Bureau of Mines

The aluminum industry spends about \$2 billion on energy—about 8.6% of the value of shipments. For primary production, the costs were \$1.55 billion or 22% of its value of shipments.

ENVIRONMENT

For each ton of aluminum produced, about 50–70 pounds of spent potliner are generated. Potliner is a hazardous waste containing fluoride, sodium, and cyanide contaminants. Fluoride emissions are also generated and must be controlled.

SELECTED OIT ALUMINUM INDUSTRY TECHNOLOGIES

To help the aluminum industry improve its productivity, OIT is sponsoring a number of related R&D efforts to develop a new inert anode/cathode system that can be used to retrofit existing smelters. The anticipated benefits of the new system include the potential to:

- ❑ Reduce energy cost by \$300 million/year
- ❑ Reduce operating costs by 10%
- ❑ Increase productivity by 25%.

The new anode will last up to 5 years, much longer than the 2–3 weeks

typical of conventional anodes. Carbon dioxide emissions and other pollutants will be reduced or eliminated.

OIT is also sponsoring a new energy-efficient calcining process to remove water from the alumina prior to smelting. This process would yield alumina with improved physical properties and reduce overall aluminum processing costs by up to 5%.

Photo courtesy of Coors Brewing Company

Beverage cans are made from secondary aluminum.

The Foundry Industry

The foundry industry is almost totally scrap-based, converting up to 20 million tons/year of scrap into castings used in over 90% of durable goods and 100% of machine tools. About 3000 foundries employ nearly 200,000 workers. Since 1980, about 25% of U.S. foundries have closed. Output in 1991 was about half of what it was in 1972. Casting imports and exports are each about 7% of the U.S. market.

ENERGY

Foundries used 0.25 quad in 1988—66% from natural gas and the remaining majority from electricity. Melting uses about 55% of the foundry industry's energy, but many furnaces are only about 35% efficient. The foundry industry spent \$3.3 billion for energy in 1992—17% of the value of shipments.

The Glass Industry

The glass industry is gradually changing from a low-value-added, commodity business to an increasingly high-value-added, specialty business. While U.S. glass output has fluctuated around 20 million tons/year since 1983, the value of glass shipments has grown from \$14.9 billion in 1982 to \$21.3 billion in 1992. The industry's principal segments are flat glass, container glass, fiberglass, and specialty glass. Fiberglass and specialty glass are the fastest-growing segments.

Extensive modernization has contributed to increased exports of flat glass, while imports have changed little. The U.S. maintains a strong trade surplus in fiberglass and high-growth, high-value-added specialty glass.

ENERGY

The industry consumed about 300 trillion Btu in 1991 including electricity losses. Melting and refining

ENVIRONMENT

About 850 pounds of spent sand, 350 pounds of slag, and 200 pounds of dust are generated for each ton of casting produced. This amounts to about 8 million tons/year of solid waste—more than 80% of which is landfilled. About 4% of the industry's waste is hazardous. Environmental regulations cost \$1.25 billion/year

*Foundry Industry Profile**

Volume of Products	11 million tons
Value of Shipments	\$19 billion
Total Employment	197,000 jobs
Capital Expenditures	\$0.7 billion
Net Trade Balance	\$-10 million (1989)
Energy Consumption	0.25 quad (1988)
Waste Generation	8 million tons of sand waste
Average Hourly Earnings	\$12.77

*Data for latest year available

use 50% to 68% of the total energy required for glassmaking. Energy costs approach \$1 billion/year, with natural gas accounting for about 80% of the costs.

ENVIRONMENT

More glass is recycled than plastics but less than most metals. Glass recycling is constrained by the low cost of raw materials and the limited scrap collection infrastructure. Fiberglass is generally not recycled. The effect of fibers used in making fiberglass is a health concern.

Another environmental concern is the glass melting process, which emits NO_x and other harmful air emissions. In 1991, glass industry pollution abatement costs totaled \$43 million for capital and \$187 million for operating expenses. Clean Air Act Amendments will require costly equipment, monitoring, and permitting.

and Clean Air Act Amendments may add \$750 million/year in costs. For small foundries, pollution control accounts for 30%-40% of all investments.

SELECTED OIT FOUNDRY TECHNOLOGIES

OIT's foundry R&D is developing technologies to help U.S. foundries improve their competitiveness while meeting strict environmental standards. For example, OIT's program has developed an economical method of recycling spent foundry sand that could reduce landfilling this waste by more than 2 million tons while reducing operating costs. R&D is also being conducted on advanced casting methods that will increase design freedom while reducing costs, energy, and emissions. Finally, researchers are developing a computer model to help foundry furnace operators run their furnaces more efficiently.

*Glass Industry Profile**

Volume of Products	21 million tons
Value of Shipments	\$21 billion
Total Employment	153,000 jobs
Capital Expenditures	\$1.1 billion
Net Trade Balance	\$0.1 billion (estimate)
Energy Consumption	0.3 quad
Waste Generation	N/A
Average Hourly Earnings	\$13.33

*Data for latest year available

SELECTED OIT GLASS INDUSTRY TECHNOLOGIES

OIT's glass program concentrates on the energy-intensive melting and refining steps. A major R&D effort recently developed an advanced furnace system that reduces the melting and refining time for fiberglass—from more than a day down to about one hour. New research efforts focus on developing more robust furnace lining materials and improved sensors to improve the accuracy of the glassmaking process.

OIT'S Crosscutting Technology Programs for the Industries of the Future

ADVANCED INDUSTRIAL MATERIALS

Advanced materials possess properties that are far superior to conventional materials such as steel, aluminum, glass, or plastics. Using advanced materials in industry can improve efficiency and productivity through reduced energy use, higher processing temperatures, longer equipment lifetimes, and reduced downtime. The U.S. leads the development of advanced materials, but their use has been slowed because manufacturing opportunities for these materials have not been adequately assessed.

In the pulp and paper industry, wear and corrosion are important issues. The paper industry's material needs include impact-resistant, cutting-edge materials; more corrosion-resistant materials for boiler tubes and surface coatings; and lightweight, polymer-based structural materials for vessels, piping, and valves.

Wear, corrosion, and erosion are also major concerns in the glass industry. The glass industry's material needs include new refractory materials, new coatings and deposition technologies, and improved material coverings for glass contact applications.

OIT's Advanced Industrial Materials Program

OIT's advanced industrial materials program sponsors the development of new alloys, particularly nickel aluminides, that can withstand higher temperatures than steel alloys and increase the efficiency of current industrial processes.

OIT is investigating new ceramic materials and material fabrication methods for aluminum production

applications and other high-temperature, corrosive industrial processes. OIT is also developing a technology to recover high-value chemicals from mixed-waste plastics and polymers that conduct electricity.

CONTINUOUS FIBER CERAMIC COMPOSITE MATERIALS

Many opportunities to improve the productivity, energy efficiency, and waste utilization of industry are limited by the shortage of materials capable of handling extremely harsh operating environments.

Though ceramics have properties that can withstand extreme heat, abrasion, and similar conditions, their tendency to crack and fail has limited their use. By incorporating long, strong fibers in a ceramic matrix, the toughness of ceramics can be improved greatly and their tendency to fail can be reduced considerably.

There are many potential applications for these materials, called continuous fiber ceramic composites (CFCCs):

- ❑ Incineration systems to help reduce waste disposal problems, decrease toxicity of air emissions, and reduce fuel use through enhanced waste energy recovery
- ❑ Gas turbines that could operate at higher temperatures and increase energy efficiency by as much as 4%
- ❑ Industrial burners and combustors
- ❑ Process equipment such as reformers, reactors, and high pressure heat exchangers for use in chemical plants and petroleum refineries
- ❑ Filters, separation, and sewage treatment systems

- ❑ High temperature industrial heating, melting, and heat-treating equipment such as furnace linings, crucibles, and racks
- ❑ Structural members such as beams and decking.

OIT's CFCC Program

OIT is sponsoring the development of low-cost CFCC manufacturing methods. A new material called Toughened Silcomp and a fabrication technique known as melt infiltration have been developed for gas turbine parts. These parts will allow the turbine to operate more efficiently with reduced emissions.

Researchers are also developing new methods to fabricate CFCCs to allow these materials to be made into burners and tubes for equipment such as boilers, furnaces, and heaters. They are also investigating CFCC diesel engine valve guide to cut particulate emissions and improve fuel economy.

ELECTRIC MOTOR SYSTEMS

Annual sales of the U.S. electric motor and drive industry are about \$10 billion and the industry employs about 50,000 people. Motor-driven equipment accounts for about 70% of industrial sector electricity use. In some industries, electric motor systems (EMS) represent 90% of electricity use. Roughly \$30 billion is spent on electricity to drive industrial EMS.

The widespread use of EMS in U.S. industry means that more efficient EMS offers significant opportunities for energy and cost savings and improved productivity. In addition,

reduced energy use through improved EMS can contribute to lower emissions, reduced waste streams, and improved environmental quality while reducing costs associated with waste remediation.

Opportunities to improve EMS efficiency include: (1) improving motor efficiency (2) reducing electricity distribution losses (3) improving the match between motor drive and the mechanical system and (4) using equipment or processes that require less power. Combined, these improvements could lower industrial power use 240 billion kWh/year by 2010.

OIT's Motor Challenge program is discussed on the following page.

SOLAR INDUSTRIAL TECHNOLOGIES

Solar energy is abundant. After installation, solar energy users get free energy. Solar energy also helps lower the generation of greenhouse gas emissions that accompany fossil fuel consumption.

Solar technologies also create jobs. Most solar technologies are designed and built by highly trained engineers and technicians. The use of solar energy is an investment in people who build technology that uses a naturally abundant resource rather than nonrenewable resources.

Solar process heat technologies produce hot water, steam and hot air for industrial use. Potential markets exist wherever large amounts of low temperature heat are required. Solar detoxification technologies can destroy hazardous organic waste such as solvents and manufacturing process byproducts.

OIT's Solar Industrial Program

OIT is collaborating with other government agencies and utility companies to leverage its resources while increasing the likelihood of an early market for solar process heat technologies. Several solar water

detoxification projects are currently under way, and a reactor for detoxifying contaminated air is being field tested. OIT is working with several partners to develop solar-based advanced materials manufacturing using the High-Flux Solar Furnace.

INDUSTRIAL WASTES

Pollution control costs are largely the cost of end-of-pipe cleanup of regulated waste. A key strategy for cutting these costs is to reduce the amount of waste by improving process yield. Improved yields increase productivity and capacity as well as reduce waste.

It is usually too costly to improve process yields to 100%—the point at which zero waste is created. Thus, certain quantities of industrial waste are unavoidable. But at the broader level of industry as a whole, the unavoidable wastes of different processes and industries can be recycled and eventually reused as inputs by other processes or industries.

Where waste reduction through process improvement or product redesign is no longer practical, waste recycling and utilization processes can help convert waste to materials or energy useful as feedstocks or fuels in other parts of the industrial infrastructure.

OIT's Industrial Waste Program

OIT's waste program aims to reduce waste and develop new uses for unavoidable waste. Projects are under way in VOC minimization techniques, asphalt recycling, electroplating waste, gasification of food wastes, use of waste tires, conversion of waste gases from carbon black into acetic acid, and recycling auto shredder residue, among many others. These technologies would reduce landfilling, emissions, raw material requirements, and the need for imported petroleum feedstocks.

MUNICIPAL SOLID WASTE

Recycling is a common municipal solid waste (MSW) option for such wastes as aluminum cans, newspapers, and glass. MSW materials recycling reduced U.S. energy demand by an estimated 110 trillion Btu in 1990. MSW combustion generates electricity, saving about 260 trillion Btu of fossil energy use.

The cost of disposing of MSW in landfills, referred to as tipping fees, has increased from about \$10 in 1982 to about \$29 in 1992 because of increased regulations and growing saturation of available landfill space.

OIT's MSW Program

The goal of the OIT MSW program is to minimize landfilling and maximize both energy and materials recovery from post-consumer wastes. The program is sponsoring (1) a pilot plant for the anaerobic digestion of tuna sludge and MSW to address serious waste issues in American Samoa and (2) research on landfill gas to develop enhanced methods for recovering such gas for use as a fuel. An effort is also under way to compile up-to-date energy, economic, and environmental data to facilitate more informed MSW decision making.

Potential Benefits of OIT-Supported Technologies

Technologies currently supported by OIT have the potential to cultivate substantial energy, productivity, cost, and environmental benefits for our Nation's industrial sector. At the same time, these technologies can support more globally competitive industries, increase the employment and wages of our country's workforce, and help boost the Nation's overall rate of economic growth. A few of the potential benefits of selected OIT technologies are summarized below. The benefits of these and other OIT technologies, plus the method for calculating these benefits, are discussed in greater detail in the full report.

CHEMICAL AND PETROLEUM REFINING INDUSTRIES

OIT-sponsored technologies such as biological production of petrochemical feedstocks, new membranes, improved catalytic processing techniques, advanced fluid catalytic cracking, and various new pollution prevention methods could help cut annual energy costs in these industries by more than \$2 billion. These technologies will provide numerous other benefits as well. For example, hybrid membrane separation of propylene has the potential to lower chemical industry operating and maintenance costs by more than \$400 million per year. Ethanol recovery from refinery waste gases could reduce petroleum refining NO_x emissions by more than 70,000 tons/year while simultaneously cutting capital costs by more than \$700 million.

PAPER AND FOREST PRODUCTS INDUSTRY

OIT is supporting a variety of technologies for this industry, including black liquor gasification, recovery

boiler modeling and control, new pulping catalysts, impulse paper drying, and others. Collectively, these technologies have the potential to reduce the industry's energy use by more than 200 trillion Btu/year and reduce its annual energy bill by more than \$600 million. These same technologies also offer the potential for significant environmental benefits. For example, recovery boiler modeling should improve the efficiency of and control over the combustion and chemical reactions occurring in these vessels and help reduce combustion-related CO₂ emissions by nearly 5 million tons/year.

STEEL INDUSTRY

Current (or recent) OIT-supported steel industry technologies, including direct steelmaking and advanced process control, offer the potential to reduce energy use by about 200 trillion Btu/year and cut annual energy costs by more than \$1 billion. OIT steel technologies also can provide substantial environmental benefits. For example, the electrochemical removal of zinc from steel scrap could enable nearly 1 million tons of off-grade scrap to be recycled. Steel plant dust and sludge recycling could reduce steel industry solid waste by more than 3 million tons/year and reduce its environmental costs.

ALUMINUM AND METAL FOUNDRY INDUSTRIES

Improved alumina calcining, inter anode/cathode reduction cells, and spray forming could help reduce energy use of the power-intensive aluminum industry by about 15 trillion Btu/year and reduce the industry's energy costs by more than \$200 million/year. OIT's foundry

technologies not only reduce energy use, but also cut down on solid waste generation. For example, the foundry sand mobile recycling unit could cut the industry's annual disposal of spent sand by more than 2 million tons/year.

COGENERATION/ADVANCED TURBINE SYSTEMS

Three OIT-supported technologies in this program possess exceptional energy-saving potential. Together, the advanced turbine system, high-performance steam system, and ceramic retrofit gas turbine could save nearly 500 trillion Btu/year and reduce industry's total energy bill by nearly \$1.2 billion. These technologies would also provide significant reductions of such combustion-related emissions as NO_x, SO_x, and particulates and cut the annual release of nearly 35 million tons of CO₂ waste gas. The gas-fired advanced turbine system would have the added benefit of substantially lower capital costs that could save industry an additional \$100 million/year.

MOTOR CHALLENGE

As the centerpiece of OIT's electric motors program, Motor Challenge consists of a variety of activities, including demonstrations, seminars, an information clearinghouse, and databases that are conducted in partnership with major motor users. Motor Challenge is an important catalyst to help industry increase its use of more efficient electric motor systems. Using efficient motor systems could annually save 400 trillion Btu of energy, cut industry's energy costs by nearly \$6 billion, and reduce the generation of CO₂ gas by more than 70 million tons.

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