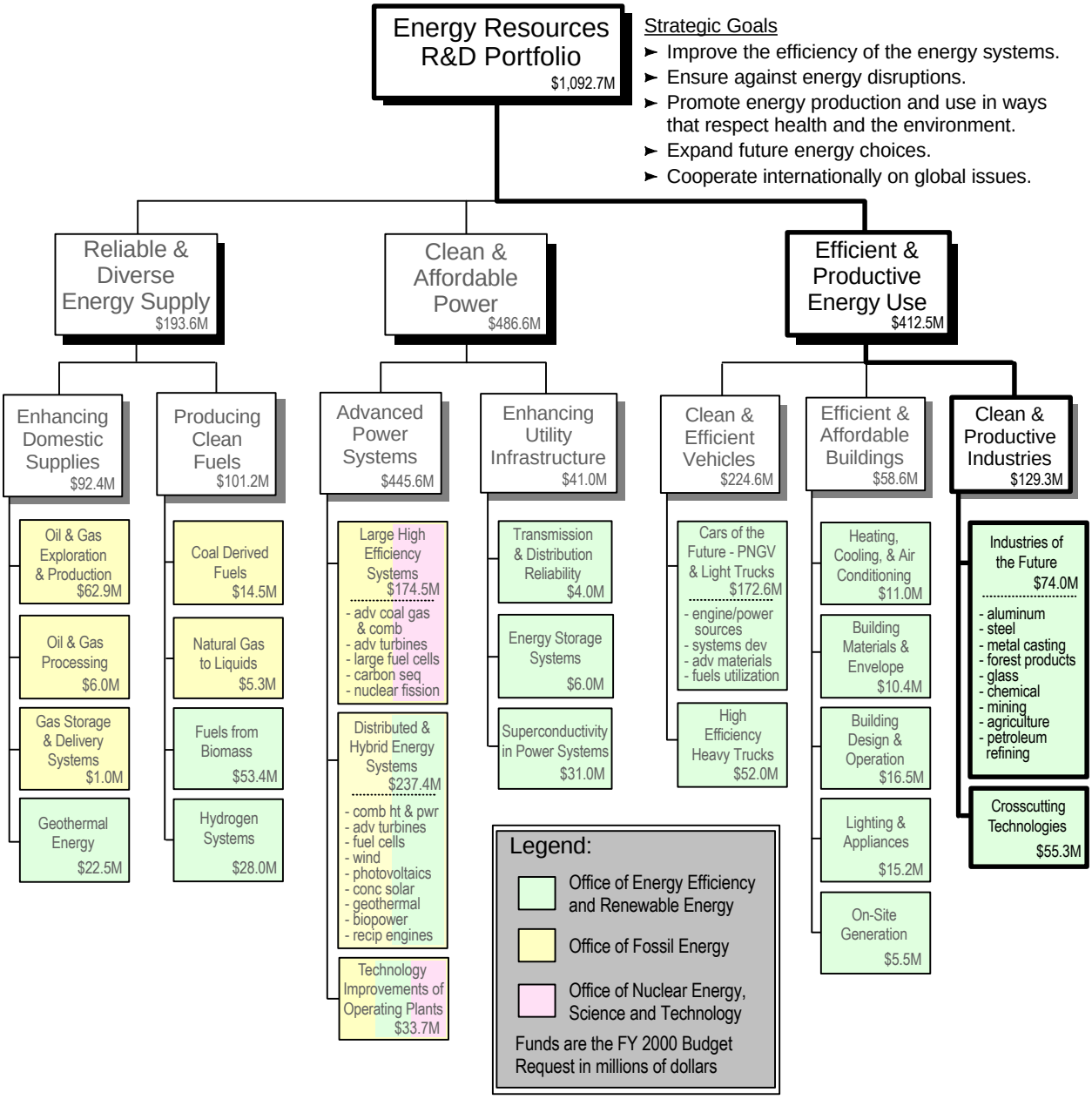
Chapter 9
Clean and Productive Industries



Chapter 9

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Table of Contents

Page

Overview . . . 231
- Definition of Focus Area . . . 231
- National Context and Drivers . . . 231
- Linkage to CNES Goals and Objectives . . . 231
- Uncertainties . . . 232
- Investment Trends and Rationale . . . 232
- Federal Role . . . 235
- Key Accomplishments . . . 235

Industries of the Future . . . 237
- Background . . . 237
- Linkage to CNES Goals and Objectives . . . 237
- Program Description . . . 238
  - Aluminum . . . 238
  - Steel . . . 241
  - Metal Casting . . . 242
  - Forest Products . . . 245
  - Glass . . . 248
  - Chemical . . . 250
  - Mining . . . 252
  - Agriculture . . . 253
  - Petroleum Refining . . . 254

Crosscutting Technologies . . . 255
- Background . . . 255
- Linkage to CNES Goals and Objectives . . . 255
- Program Description . . . 255
  - Enabling Technologies . . . 256
  - Technical Assistance . . . 259
  - Financial Assistance . . . 261

Summary Budget Table . . . 263

Overview

Definition of Focus Area

The clean and productive industries research and development portfolio focuses on generic pre-competitive research concentrating on cooperative projects with nine of the major process and extraction industries in the industrial sector. These industries, referred to as the Industries of the Future, include aluminum, steel, metal casting, forest products, glass, chemicals, mining, agriculture, and petroleum refining. In addition, the portfolio includes crosscutting research and development efforts on technology needs which have been identified in technology roadmaps across multiple industries, and which form technology bases from which more industry-specific developments can derive. The cross cutting activities also include technical information and outreach programs, demonstrations, training, and tool development which assist industry in evaluating and adopting these new energy efficient and pollution preventing technologies and techniques.

National Context and Drivers

Industry consumed almost 34 quads of primary energy in 1994—about 38 percent of all energy used in the United States The industrial sector contains extraction, and material processing and product manufacturing industries. Over 80 percent of the energy consumption in manufacturing (including feedstocks) occurs in only seven process industries: aluminum, steel, metal casting, forest products, glass, chemicals, and petroleum refining. Mining and agriculture are major energy users in the extraction industry. These nine industries are highly capital intensive, produce significant emissions and waste products with far larger energy and pollution abatement costs per unit sales, and typically invest far lower percentages of sales into research and development than the U.S. average. Overall energy intensity (energy per unit output) decreased from 1973 through 1986, but has since remained nearly level, while pollution abatement costs have continued to grow; due in significant part to energy consumption.

The major process industries are, and are becoming increasingly, highly capital intensive. Markets are continuing to become increasingly globally competitive. Many, such as steel, faced dire times in the 1960s and 1970s. They restructured and re-engineered themselves such that by the 1980s, they were world leaders. By the late 1990s, world financial markets, trade issues, increasing costs of environmental abatement and other costs, not necessarily shared by foreign competitors, and generally soft markets have again placed major strains on these industries. Reducing energy costs and reducing waste and reducing or eliminating environmental emissions upstream (closely related to energy use), are increasingly being recognized as controllable costs that can lead to increased productivity and profitability, increased product quality, and increased global competitiveness.

Linkage to CNES Goals and Objectives

The program is in direct support of CNES goal and objective:

- CNES Goal I, Objective 2 - Significantly increase energy efficiency in the transportation, industrial, and buildings sectors by 2010.

A reasonably ambitious goal for industry for the year 2010 is a 25 percent reduction in energy consumption per unit of output. The strategy to support the achievement of this goal, in addition to focusing resources on the most energy and waste intensive industries, is to partner with and across industries, and align industry and government resources to areas of greatest need.

Uncertainties

In addition to the normal uncertainties in the R&D process, timing uncertainties are in some industries of particular importance. Many large plants and large equipment modules were installed in the rapid economic growth period after WW II through the 1960s. These will be reaching their useful life by the end of the next decade. Hence, a window exists where the new technologies, if developed in time, may be adopted rapidly during the expected new or retrofit installations; if that window is missed, adoption will be slower in the face of recently installed high capital investment facilities. In addition, several of the major process industries are operating at very low or negative profit margins due in large part to low global prices associated with the current Asian and Eastern European economic situations. The restructuring of the utility industry, climate change, and emission requirements also have the potential for significant impacts, but the magnitude, and even the direction, are subject to the details of actual implementation; many of the details are also associated with State and local policies.

Investment Trends and Rationale

The program focuses its resources principally on the nine industries referenced above and referred to as the Industries of the Future (IOF). It supports collaborative research, development, and demonstration efforts to accelerate the development and adoption of energy efficient technologies and the incorporation of best practices in industry.

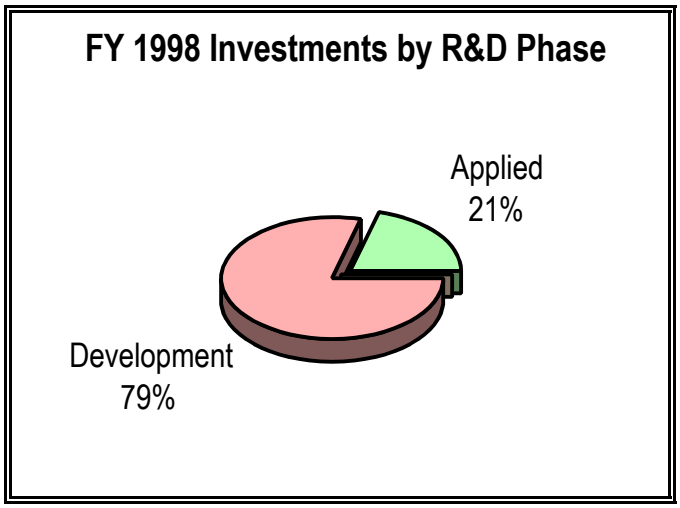
The IOF process includes:

- *Facilitate industry visions and technology roadmaps.* Industry leaders outline a future *vision* of their industry that is defined by explicit market, business, and technology goals. A *technology roadmap* is developed to articulate specific technology strategies and create a comprehensive R&D agenda. DOE's Office of Industrial Technologies (OIT) assists industry during this process and acts as a neutral party that can bring together competitors, suppliers, customers, and other key stakeholders.

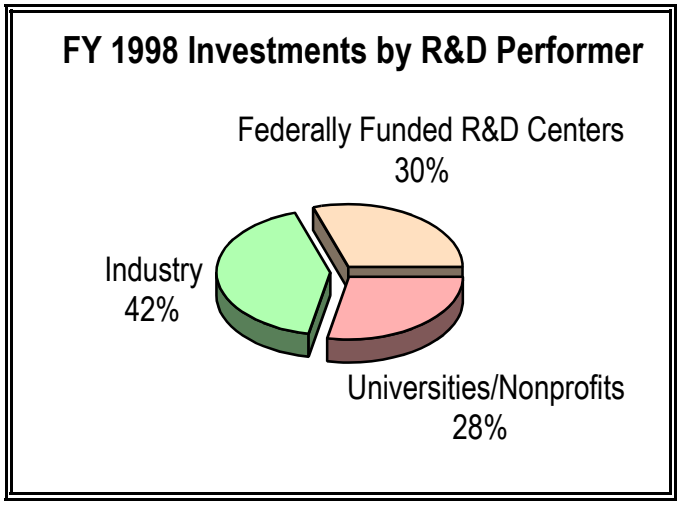
- *Cooperatively fund strategic projects.* Once industry has developed its technology roadmap, OIT selectively cost-shares technology projects contained within the roadmap that are consistent with the Department's strategic goals and the government role.

Essentially all research projects and research performers are selected through a competitive solicitation, with direct industry involvement in the process with universities, DOE laboratories,

and private sector companies performing the research. A significant number of efforts involve a mix of performers including industry-laboratory-university teams or combinations thereof. These mixes vary from industry to industry and the process is flexible to be responsive to the diverse nature of the different industries. The ratio of investments by R&D performer are shown in the figure below, however it should be noted that at the present time the estimates are based on the funding of the initial and primary recipient and do not reflect the sometimes significant percentage of funds flowing to subcontractors or collaborators which may be a different category of performer.



The strategy also includes providing an integrated set of activities ranging from the applied research phase through technology development to activities to accelerate the continued development and/or adoption of energy efficient technologies such as demonstrations of advanced technologies and best practices tools and training on both industry-wide and plant floor levels. An estimate of the ratio of investments by phase of research and development is shown in the figure below. Research is conducted principally at the industry-wide, pre-competitive stage,



with results available to all industry participants, rather than individual members of the IOF industries. Typically, the industry partnership is spearheaded by one (or occasionally more) industry trade association and/or professional society. Participation and consensus by the majority of the industry members is involved and individual companies provide staff for technical roadmapping teams, peer and program reviews, and other support. Projects and programs are cost shared, generally with IOF industry collaboratives to average at least 50 percent over the program's life.

Major program trends over the FY 1997 to FY 2000 time period include:

- The program initially focused on seven major process industries, temporarily decreased to six when one industry was unable to reach a consensus. That industry has since reached a level of consensus and in addition, mining and agriculture (in particular the bioproducts area of agriculture) have been added to the Industries of the Future portfolio. This represents a balancing of available resources and the major energy consuming industries; further expansion is not anticipated at current resource levels in order to maintain that balance. In addition, the development of IOF programs at the State level is being initiated providing closer relationships between State and Federal programs and promising more efficient development and adoption of technologies by local industries.

- The needs for advanced sensors and controls and advanced combustion technologies have been identified as a high priority need in many industry roadmaps, hence a focus and new applied research efforts in those areas have been initiated to help provide the technology base from which industry-specific sensors and controls and combustion components can be developed. In addition, the prior research portfolios for each industry have, by FY 1998, been revamped to match industry developed technology roadmaps. Most recently, the Chemical program has been reoriented and a catalysis program developed to support it. All FY 1998 catalysis research projects are new, replacing other prior efforts which were completed or terminated.

- Increasing integration of the totality of products and services provided by the industrial RD&D programs has been undertaken and is expected to be fully implemented in FY 1999. In this integration, industrial customers are made aware and encouraged to adopt technologies developed in other programs. For example, while the Aluminum program is developing, in collaboration with the aluminum industry, advanced aluminum processing technologies, more efficient technologies, tools, or techniques arising from other programs, such as in electric motor systems, steam, and compressed air, are being presented to the industrial customers along with a more overall system view of energy use and needs. Increasing collaborations with State energy technology institutes, and State energy and economic development and similar agencies, are also envisioned as an approach to assist the adoption of new technologies at the State and local level as well as to further the identification of State and local level needs into the national roadmapping process.

Federal Role

The energy consumption by industrial processes is intimately tied to emissions and environmental impacts as well as to productivity and economic competitiveness. In turn, this has major implications for the overall environment and the economy, affecting U.S. jobs and global competitiveness. This is particularly so in the major process and extraction industries, where global competition is not always based on completely free markets and where profitability as a function of sales is, in many cases, relatively low. In turn, this necessarily leads to relatively low private sector investments in R&D (as a function of sales) by these segments of industry as compared to industry as a whole.

The levels of risk involved in the adoption of major new technologies in these industries is also relatively high. Most process plants operate continuously at very high throughputs; down-times and retrofits or repairs associated with some new technology could be financially critical. These processes are also very highly capital intensive and involve plants with generally very long, even half-century, lifetimes. Competition for capital and the nature of the downside risks further hinder adoption of many new technologies. Less capital intensive advances such as process parameter changes or advanced sensing and controls and simulation capability suffer from relatively limited capability to maintain intellectual property.

Collectively these factors lead to individual companies being unable, or rationally unwilling, to invest in many areas of advanced R&D. Hence there is a need for a Federal role in helping to support, primarily, generic, pre-competitive R&D which can benefit the industry as a whole, from which individual companies can then further develop in a competitive environment, and which would be unlikely to occur without such Federal involvement. Further, it leads to the need for testing, verification, demonstration, and information dissemination to provide the levels of information needed for critical investment decisions for the rapid adoption of advanced technologies.

The program acts initially as a facilitator, assisting industry in coming together in order to collectively identify issues and develop an industry-wide vision of their long-term future. The program further facilitates and assists in the development of an industry technology roadmap which identifies and prioritizes the research and development needed to achieve that vision. The program then, in collaboration with the private sector, collaborates and cost-shares the generic pre-competitive research and development activities which meet industry priority needs and the Department's key missions. This role also involves bringing to bear the unique expertise and facilities of the National Laboratories to attack key technological and scientific problems.

Key Accomplishments

The industries participating in OIT's program are at some stage in developing a vision of where they want to be in 2020, and a roadmap for developing technologies in order to reach their goals. Some of the industries have embarked on R&D following their roadmaps, and have reported successful results from that R&D. The accomplishments of the nine current Industries of the Future include the following:

Aluminum Industry: The vision and roadmap documents are completed. The Inert Anode roadmap is also completed. Cathode research has achieved an 8 percent energy savings with a new cathode technology tested in a pre-bake cell, with no decrease in aluminum production.

Steel Industry: The vision and roadmap documents are completed. Several research projects were highlighted at Burns Harbor Showcase, 1998, including "Nickel-Aluminide Materials for Rolls in Steel Reheat Furnaces," whose use will save 6 trillion Btus/yr across the industry, and reduce production costs and waste. Direct Ironmaking technology is close to commercialization and will reduce energy use 25 percent in production of molten pig iron.

Metal Casting: The vision and roadmap documents were completed. The Lost Foam Consortium led to advances for reducing defects and producing higher-quality lost foam castings. By 2010, use of the technology will save 4.6 trillion Btus of energy and prevent 0.45 million tons of waste.

Forest Products: The vision was produced and "research pathways" have been defined. New cleaning technology allowing the use of lower grades of recycled paper by papermakers will permit 50 percent recycling of all paper used, reducing energy used for recycling by 0.l quads/year and lowering CO_2 emissions by 0.6 million tons annually.

Glass: The vision and roadmap were produced. Oxy-fuel firing for glass melting furnaces is in commercial use in 20 percent of glass furnaces, reducing a manufacturer's fuel use by 48 percent, NO_x emissions by 70 percent, and particulates by 60 percent, and increasing productivity by 25 percent. Advanced optical sortation removes over 90 percent of ceramics from glass cullet and sorts glass by color, saving 1 million Btus annually, and leading to 100 percent recycling of consumer glass.

Chemicals: There is a vision document, but the complexity of the industry requires several roadmaps, three to date. A membrane recovery system for volatile organic compounds (VOC) won an award from American Institute of Chemical Engineers. A novel process for producing nontoxic lactate ester solvents also received a national award, which has the potential for replacing 80 percent of the 3.8 million tons of halogenated toxic solvents used annually in the United States.

Mining: A vision document has been finished and roadmaps are in preparation. A compact was signed between DOE and the National Mining Association in May 1998.

Agriculture: A vision document was published focusing on plant-based renewable resources as a long-range goal. A compact was signed by representatives of the U.S. agricultural, forestry, and chemical industries, DOE, and the United States Department of Agriculture (USDA).

Petroleum Refining: A vision document is expected in FY 1999, and future collaboration with DOE is expected based on direct and indirect energy-efficiency technologies.

In the Cross-Cutting Technologies area:

Advanced Materials: Engineered ceramics are being tested and developed for high-temperature applications, e.g., continuous fiber ceramic composites (CFCC) hot gas filters will be tested in a chemical plant in FY 2000; and advanced industrial materials are focusing on advanced intermetallic alloys, with a new class of metal matrix composites expected by FY 2000.

Combustion Technologies: A vision and roadmap document were developed; oscillating combustion technology for reducing energy use in steel reheat furnaces is being tested at Bethlehem Steel's Burns Harbor, Indiana, mill. Research is also planned for improved controls and sensors, and increased systems integration**.**

Sensors and Controls: A need for improved sensors and controls has been identified in most of the technology roadmaps produced to date. There is a program goal to have, by 2009, significant advancements in the underlying science and technology of intelligent control systems.

Technical Assistance: This is a program to bring the full range of OIT's technical assistance and technologies to thousands of plant sites, in an integrated package that is easy for industrial partners to access. A recent highly successful showcase at Bethlehem Steel's Burns Harbor, Indiana, plant demonstrated a large number of advanced energy efficient technologies to representatives across the steel and other industries. Sub-divisions of this strategy include the Motor Challenge Program, that has already increased the use of advanced energy-efficient motors at the 3M Corporation; Steam Challenge, as part of the Motor Challenge, to provide technical assistance on steam and compressed air systems; and the Industrial Assessment Center Program, that has pinpointed and analyzed opportunities in over 7,000 small manufacturing sites for saving energy, reducing pollution, and increasing productivity.

Financial Assistance: This program contains two subdivisions: Inventions and Innovation, that, for example, provided funding to a corporation to develop a technology for the automated production of mold or die blocks (the LOM process), and the National Industrial Competitiveness through Energy, Environment, and Economics program (NICE^3), that, as another example, helped a company develop a new plating technology that reduces energy and eliminates wastes.

Industries of the Future:

Budget: FY98-$53.1M, FY99-$57.5M, FY00-$74.0M

Background

The nine Industries of the Future have developed (or are in the process of completing) technology roadmaps addressing their industry vision and their major priority technological needs. Competitively selected projects and performers are underway to perform research, develop, test, and accelerate the adoption of new energy efficient technologies.

Linkage to CNES Goals and Objectives

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Program Description

Research and development programs, along with testing, demonstration, and evaluation, are undertaken on a broad array of technologies, identified by each industry in their Industries of the Future technology roadmaps as priority and which also meet the Department's missions and goals. Individual projects range across the spectrum from small focused research tasks and activities of relatively short duration to multi-year, major technology development projects and across the gamut of individual technical disciplines and multi-disciplinary research. The nature and balance of the portfolios of activities vary based on the characteristics and needs of each industry and are described below.

Aluminum

Budget: FY98-$7.3M, FY99-$8.1M, FY00-$11.2M

Description, Objectives, and Performers. Nearly ½ quad of energy is used in making primary aluminum and about 150 trillion BTU are used in secondary aluminum production and rolling, making products worth $35 billion per year. The industry spends nearly 7 percent of its product costs on energy, a larger portion than that spent by other industries. The production of primary aluminum produces 6 MMTCE per year from energy, mainly electricity, use. In addition, the basic smelting of alumina utilizes consumable carbon anodes which contribute about 1.5 MMTCE. The process also produces over 4 MMTCE from perfluorocarbons.

The aluminum industry and DOE signed a compact in October 1996, having produced a vision document in 1996. A technology roadmap was published in May 1997. Because of the importance and difficulty of developing a replacement for the current carbon anodes, a follow-on roadmap, Inert Anode Roadmap, addressing this complex area, was published in February 1998.

The vision and roadmaps identified specific goals adopted by the industry which include:

- Improve the energy efficiency of the smelting process by 13 percent within 10 years and by 27 percent in the longer term.
- Eliminate (process-produced) CO_2 emissions in the long term.
- Develop new uses for wastes/byproducts to reduce waste emissions and improve efficiency and costs.

R&D Challenges. The aluminum industry roadmap organizes technology needs into three categories: Primary (including recycling) Aluminum Production; Semi-Fabrication Production (subdivided into Casting and Rolling/Extrusion); and Finished Products. (DOE will be supporting the first two categories; finished products are left for private sector R&D). They are further prioritized and categorized into short-, mid-, and long-term needs. DOE's overlaid priorities stress the smelting portion of primary aluminum production (since the major of energy use and emissions occur in that process) as well as methods to improve production from recycled aluminum, which only consumes about 5 percent of the energy as primary production.

The main challenge involves eliminating the inherent deficiencies in the traditional Hall-Heroult process. The process involves a carbon anode with molten cryolite (a sodium-aluminum-fluorine compound) as the electrolyte and molten aluminum acting as the cathode in an electrolytic cell. Electric energy plus consuming of the carbon anode leads to conversion of the raw alumina (Al_20_3) to aluminum plus CO_2. Variability in the process causes the emissions of perfluorocarbons. Electricity losses occur for several reasons including anode-cathode spacing requirements, partly due to undulating melt surfaces. The consumable carbon anode is also a major economic expense due to two-three week replacement. Improved cells in the short term leading to a totally new process in the longer term is the principal challenge.

R&D Activities. *Primary (including recycling) Aluminum Production*
Cathode research is investigating wettable TiB_2 cathodes and recent tests showed an 8 percent lower energy consumption over conventional cells. The wettable ceramic cathode, by eliminating the wavy irregular molten surface, allows the anode-to-cathode distance to be decreased, reducing electrical resistance. Research is continuing on materials, scaling issues, stability and molten surface motions. If successful, commercialization by industry partners is expected by 2003.

Exploratory research on two advanced cell designs and several advanced anode materials was recently initiated. Statistical design and retrofit tests will be used to determine the most promising anode-cathode coupling and geometry. A retrofit advanced cell system will also require R&D on cell sensors and controls, advanced sidewall materials, new designs for cell heat control and management, as well as Bayer process improvements.

Other cell research including investigation of advanced sensors using fiber optic probes and laser-based Raman spectra analytical techniques, probe coating materials to survive cryolite melt temperatures, sensors to detect and reduce chloride salts in molten aluminum, and dynamic modeling to enable better control of cell and electric power load levels are all necessary to achieve significant cell improvements, stability, and reliability.

Some 800,000 pounds of aluminum salt cake (spent salt fluxes, residue oxides, dross, etc.) could be saved and aluminum (and its energy content) and other byproducts reclaimed through reprocessing, which would provide major stimulus to aluminum recycling as well aid primary production. Four advanced processes have been examined and concentration is on

an electrodialysis technique as the most promising. Hydrometallurgical processes to improve the purity of nonmetallic byproducts (NMP) is also underway. Converting NMP to fiber insulation is in early commercialization by industry while research on alternative byproducts and electrodialysis is expected to reach pilot demonstrations by 2000-2001.

Several aluminum companies (Reynolds Metal Company, Aluminum Company of America (ALCOA), Alcon Aluminum Corporation, Kaiser Aluminum Corporation), other companies, ORNL, ANL, Carnegie Mellon University, Massachusetts Institute of Technology (MIT), and several other universities are involved in this program; several companies have developed commercialization plans pending successful R&D results.

Semi-Fabrication

The production of sheet, extrusions, and other intermediate products is a second area with potential for energy, waste, and environmental improvements. An innovative spray forming technology to form sheets, in place of the current ingot casting, as well as near-net-shape products directly from the melt (reducing reheating steps), is under investigation. Better metallurgical and corrosion-resistant properties are possible due to better microstructure control. A linear spray nozzle has been developed and thermomechanical processing studies, microstructural characterization, and mathematical and numerical modeling is underway. Energy savings of 25 percent over ingot casting/hot rolling and cost reductions of over 10 percent are expected. Goals of +/- 2 percent profile flatness and porosity targets of <4 percent have been set. An advanced development unit which can operate in both an experimental and a pilot semi-production mode is expected to start operation by 2000. ALCOA, Air Products and Chemicals, Inc., Carnegie Mellon University, University of California, MIT, and others are involved. It is anticipated that licensing the technology broadly, with royalties back to the government and participants will occur if successful.

An additional method of producing near-net-shapes is an innovative semi-solid material (SSM) process. Cast parts are produced from a slurry kept at a temperature between the solidus and liquidus isotherms exhibiting both solid- and liquid-like behaviors. It can combine the advantages of both liquid metal casting and solid metal forging. This is a longer-term, more advanced technology and the current objective is to achieve a better understanding of the fundamental issues concerning material behavior. Research includes numerical simulation to predict die filling and, ultimately, die design optimization; fluid models modified to account for the two-phase nature, obtaining rheological data needed for the modeling, and the effects of slurry structure on flow behavior and separation. If successful, energy reductions due to lower temperature processing and increased productivity due to shorter solidification times and longer die life will occur; quantified goals await further research. Participants include MIT, Worcester Polytechnic Institute, and ORNL; consortia of over 20 industrial partners are cost-sharing and will share in the research results.

Accomplishments. An early version of a new technology cathode element was tested in a full-scale pre-bake cell in a collaborative project between DOE, Kaiser Aluminum Corporation, and the Reynolds Metals Company at a Kaiser plant. Test results showed an 8 percent energy savings compared to a conventional cathode with no decrease in aluminum

production, although continued research is required to provide the required long-term material strength and longevity.

Steel

Budget: FY98-$9.7M, FY99-$10.5M, FY00-$10.6M

Description, Objectives, and Performers. The steel industry uses about 1.8 quads of energy and emits about 35 MMTCE to produce about 100 million metric tons of steel annually. This energy costs some $7.0 billion annually and represents 20 percent of total production costs. Over 50 percent of new steel production is made from recycled scrap. Steel production is a major generator of carbon dioxide and other pollutants, and the industry has invested more than $6 billion in control equipment in the last two decades.

The industry's vision document "Steel: A National Resource for the Future" was released by the American Iron and Steel Institute (AISI) and Steel Manufacturers Association (SMA) in May 1995; an R&D compact was signed by DOE and the AISI and SMA in May 1995; and a technology roadmap was released by the steel industry, as represented by AISI and SMA, in March 1998. Research priorities emphasize energy efficiency, environmental protection, greater use of recycled steel, reduced capital intensity, less waste production, and improved productivity. Long-term goals of the industry included zero waste production, and recycling of 70 percent of scrap steel.

R&D Challenges. Four key areas were identified by industry: (1) production efficiency, (2) environmental engineering, (3) recycling, and (4) product development. DOE collaborates in the first three of the four areas. A long-term high priority challenge is the ability to develop alternative iron smelting processes that produce liquid iron directly from coal and ore fines or concentrate. This would eliminate the steps of cokemaking and blast furnace ironmaking, in turn leading to much reduced costs, energy consumption, and emissions. Also a major challenge is need to develop net-shape casting processes that could enable the cast surface to become the finished part surface. This requires a degree of consistency and near defect-free continuous cast steel that is not achievable by current technology. The ability to provide real-time optimized computer-based control of the entire process and production cycles, with the necessary improvements in modeling, sensors and controls, to the accuracy necessary for substantial improvement also requires significant advances from today's technology.

R&D Activities. *Production Efficiency*
Research in this area includes advanced process control projects to improve the efficiency and productivity of major pieces of process equipment though better sensors and more rapid and precise control of the process. For example, "Microstructure Engineering in Hot Strip Mills," a computer tool, is being developed by the University of British Columbia and the National Institute of Standards and Technology (NIST) to provide on-line control over the quality and yield of hot-rolled steel. Sandia National Laboratory, Berry Metal Company, and others are developing sensors for the basic-oxygen-furnace (BOF) capable of on-line measurement of off-gas temperature and composition and bath temperature from within existing oxygen blowing lances. Both these technologies are undergoing field testing at Bethlehem Steel's Sparrows Point, Maryland, plant. A temperature measurement technology

using phosphor thermography developed at ORNL is being further developed by ORNL, the University of Tennessee, and Bailey Engineers to assure accurate on-line temperature control of galvannealing furnaces.

Environmental Engineering
Research is aimed at reducing NO_x emissions and increasing efficiency in combustors for various steel processing applications. Typical of the combustors under development is the "VISTA Combustor for Very Low NO_x Emissions in Furnaces and Boilers" which can theoretically reduce NO_x emissions to less than 10 ppm after the second stage. The low-emissions burner can be retrofitted to intermediate-temperature industrial systems to meet environmental standards, increase energy efficiency, and improve mill productivity. The Thermo Power Corporation and John Zink Company are conducting this research.

Recycling
Projects include "Atmospheric Gas Recovery and Regeneration in Heat Treating Operations," a membrane technology for recovering, cleaning, and reusing more than 90 percent of the furnace atmosphere gas discharged in present systems after carburization. The technology also removes air pollutants, avoids the production of waste, and offers the potential for heat recovery from the clean gas. Partners include the Dana Corporation and the State of Minnesota.

Accomplishments. The Burns Harbor Showcase, in May 1998, highlighted the successful implementation of several OIT-supported technologies at an operational steel plant. For example, rolls made of "Nickel-Aluminide Materials for Rolls in Steel Reheat Furnaces" are stronger and more durable than conventional rolls, and are expected to last 10 times longer with less downtime. Their use can save 6 trillion Btus per year in the industry, reduce production costs, and minimize waste. Additional success stories at Burns Harbor focused on the technologies for "Oscillating Combustion" and "Temperature Measurement of Galvanneal Steel."

Licensing agreements for the Direct Ironmaking technology developed by DOE and the American Iron and Steel Institute (AISI) are in the final stages of being signed by a major international equipment supplier to the steel industry. This technology would replace the coke oven/blast furnace process and provide energy savings of up to 25 percent in production of molten pig iron.

Metal Casting

Budget: FY98-$5.5M, FY99-$5.7M, FY00-$5.8M

Description, Objectives, and Performers. In the United States, castings are used to produce 90 percent of all manufactured durable goods and nearly all manufacturing machinery. The United States produces 20 percent of the world's cast products, and shipments are expected to reach 14.9 million tons in 1998, with sales worth $28.3 billion. Metal casting is highly energy-intensive, using 0.25 quads annually; energy expenditures in 1994 were $1.1 billion, equal to 5 percent of the value of that year's shipments. This industry recycles 13.3 million

tons of scrap annually, generating $3.5 billion in cost savings, but spends more than $300 million on pollution control technologies and produces 1.6 MMTCE.

The industry's vision document, "Beyond 2000: A Vision for the American Metal Casting Industry," was printed in September 1995, and a compact between the industry and DOE was signed in October 1995. Seven critical areas were identified: market development; materials technologies; manufacturing technologies; environmental technologies; human resources, education, and training; health and profitability; and partnerships and collaboration. A series of key challenges included reducing energy consumption by 20 percent by 2020. Additional goals relevant to DOE included: developing materials technologies; developing advanced manufacturing technologies to increase productivity 15 percent and reduce average lead times 50 percent; developing environmental technologies to achieve 100 percent recycling of pre- and post-consumer waste, a 75 percent beneficial re-use of foundry by-products, and total elimination of waste streams; and encouraging partnerships and collaborations.

The "Metal Casting Industry's Technology Roadmap Workshop," published in January 1998, identified top priority research needs including the development of low-cost, rapid tooling technology for both making and changing metal casting tooling, and improvement in the ability to produce the desired size and dimension of castings, and developing modeling technology for casting processes to gain precise understanding of how die-casting dies actually fill.

The Cast Metals Coalition (CMC) is a collaborative entity responsible for identifying R&D activities; soliciting and reviewing proposals; recommending proposals to DOE; overseeing cost-share; and managing and evaluating selected projects. The CMC is composed of representatives from the three primary associations representing the metal casting industry: the American Foundrymen's Society, North American Die Casting Association and the Steel Founders' Society of America.

The research is principally performed by universities; utilizing 88 percent of program funds with over 18 universities having been involved.

R&D Challenges. Current metal casting processes are diverse and vulnerable to the stringent environmental regulations and increased global competition. The thermodynamics and fluid flow of molten metal into and throughout molds is a complex dynamic phenomenon with a multiplicity of poorly understood factors. Small variations in internal surfaces, mold materials, initial temperatures and cooling rates, internal geometry, the molten metal's specific properties, and many others can have a significant effect on the end product. Moreover, the energy consumed in the overall process, as well as the imbedded energy in the cast product and waste (including rejects and excess material—hence the importance of near net shape casting) is significant and can be reduced by better understanding of the complex molding process. Inclusions, product characteristics and tolerances, weaknesses, costs, reject rates, throughput, are all factors which affect the capability of the industry. Research in low-cost rapid tool making with superior materials, defect-free and dimensional control of castings, advanced sensing and modeling capabilities, improved design standards, and re-use

of foundry sand and other solid wastes will make the metal casting industry the preferred supplier of near net-shape metal components beyond the year 2000. Projected benefits by the year 2020 include 10 percent market increase, 0.018 quads of energy savings, 100 percent pre- and post-consumer recycling, and 75 percent re-use of foundry by-products.

R&D Activities. The program is co-funding research in the areas of materials technologies, manufacturing technologies, products and markets, and environmental technologies.

In the area of *Materials Technologies*, the program is co-funding fundamental research to advance technology for producing clean, machinable gray iron, and ductile iron parts. By improving machinability, closer tolerances can be obtained between pistons and cylinder walls thereby improving fuel efficiency in automobiles and trucks. In another project, "Improve the Die Life of Die Casting Dies of H-13 Steel," researchers published a database of physical and metallurgical properties of H-13 steel to predict die properties during the heat treating cycle. They also developed a PC-based computer model for use in the die casting industry to optimize mechanical properties with minimal distortion.

In the area of *Manufacturing Technologies*, research is conducted on tools, sensors, and modeling to improve die-cavity filling for higher quality castings, extending die life, and minimization of part distortions for die-casting aluminum, magnesium, and zinc alloys. Guidelines are being developed for advanced casting technologies to produce higher quality, higher integrity castings.

In the area of *Environmental Technologies*, the program co-funded an evaluation of energy use in foundry industry processes including melting, molding, cleaning and finishing, and pollution control. An Energy Manual and Spreadsheet model were developed to assist the industry identify major energy load centers and to identify measures for reducing energy consumption.

In the area of *Products and Markets*, the program is co-funding research in the Development of Database Design Rules for Cast High Alloy Steel Components. These materials have properties which allow casting designers to use thinner walls, which will reduce energy costs in product markets.

Accomplishments. The Lost Foam process advantages of reducing machining, minimizing assembly operations, and reducing solid waste and emissions were never realized due to a lack of knowledge of the process and the absence of proper control measures. The Lost Foam Consortium, funded in part by the program, led to advances in controlling the lost foam process including new procedures introduced in lost foam casting as well as control technologies. These measures have been proven in the foundry in reducing defects and producing higher quality, higher precision lost foam castings. Specific developments include a single stage air gauging system followed by a 30-channel commercial air gauge for rapid determination of pattern dimensions; instruments and transducers for measuring vibrational frequencies and amplitudes; a distortion gauge to determine when and under what conditions pattern distortion occurs; instrumentation for measuring gas permeability of pattern coatings;

and a procedure to measure liquid absorption characteristics of liquid pattern pyrolysis into castings. Since 1990, there has been a significant increase in the use of the process and by 2010, about 29 percent of aluminum castings and 15 percent of iron castings are expected to be cast using lost foam technology, equating to energy savings of 4.6 trillion Btus/year by 2010, environmental savings of 0.45 million tons of waste, and energy cost savings of $16 million.

Forest Products

Budget: FY98-$12.0M, FY99-$12.0M, FY00-$21.1M

Description, Objectives, and Performers. The U.S. forest products industry represents 8 percent of the manufacturing sector's total annual output, and had shipments valued at more than $277 billion in 1995. With 1.6 million employees, the industry is a "top-10" manufacturing employer in 46 States. Although the industry uses renewable biomass fuel for 57 percent of its energy needs, it remains among the most energy-intensive of the Industries of the Future, consuming 3 quads of energy annually at a cost of $8 billion. Pollution abatement measures add about $3 billion annually in both capital and operating expenditures to the industry's production costs. Annual production of hazardous wastes is more than 2l9,000 tons. Emissions of direct carbon equivalents were 36 MMTCE in 1994.

A compact for cooperative research with DOE was signed by the forest products industry in 1994. "Agenda 2020: A Technology Vision and Research Agenda for America's Forest, Wood and Paper Industry," was prepared in November 1994. This vision document defined six areas that were considered high-priority for future R&D efforts: (1) Sustainable forest management, (2) environmental performance, (3) energy performance, (4) improved capital effectiveness, (5) recycling, and (6) sensors and control. Although no formal technology roadmap has yet been published, "Research Pathways" have been defined to specify current and future research needs for each of the high-priority research areas.

R&D Challenges. The forest products industry faces significant R&D challenges to meet changing standards and regulations while remaining economically viable and competitive. The industry's high capital intensity and the resulting economic consequences of equipment replacement tend to limit experimentation, development and application of large, new core technologies. One of the major technical issues facing the paper industry deals with the environmental impact of mills. A zero discharge concept has been envisioned by the industry called "mill closure." Current separation technologies do not adequately control or remove the non-process elements that build up in the reused water streams. Inherently more efficient, safer, and lower cost process technologies and systems are needed. Currently targeted is a replacement technology for the Tomlinson Chemical Recovery Boiler, one of the major components of current paper process technology. Existing recovery boilers are expensive to construct and operate and involve significant environmental and safety issues and costs. Most were constructed during the 1950s and 1960s and are nearing the end of their effective lifetimes; hence, a window of opportunity exists over the next decade in which to introduce major new approaches. Advanced black liquor gasification technologies hold the promise of significant improvements to performance, environmental and safety benefits, and energy and

economic improvements, but will require advances in materials, sensors and controls, and system operating parameters.

R&D Activities. *Sustainable forest management*
R&D is being directed along four different "research pathways" to achieve more productive and environmentally sustainable tree stands: biotechnology, tree physiology, soils, and remote sensing. An example of currently funded research is the use of biotechnology to improve wood properties in loblolly pine and hybrid poplar, is "The Development and Validation of Marker Aided Selection Methods for Wood Property Traits." "Trees Containing Built-In Pulping Catalysts," is studying the natural production of anthraquinone (AQ) by trees. AQ is a pulping catalyst that will reduce the need for commercial catalysts to degrade the lignin and brighten the pulp, lowering the industry's production costs and improving its productivity. Research will be funded in FY 2000 in support of these four research pathways.

Environmental Performance
DOE is currently partnering in a research pathway to develop alternative processes that prevent pollution, such as "A New Freeze Concentration Process for Minimum Effluent Processes in Bleached Pulp Mills," in which volatile and complex contaminants are concentrated in the effluent when the water content of the effluent is removed as ice—the water removed as ice can be reused in the process. A "High Efficiency ClO_2 Delignification" project will also shed light on the fundamental chemistry of chlorine dioxide delignification and reduce the use of chlorine by the industry, lowering industrial emissions. Another pathway identifies employing effective treatment methods, and includes "Reducing Emissions of Volatile Organic Compounds" through an economical biological treatment system for high volume, low concentration gas streams. For the longer term, research is also expected to target understanding margins of environmental safety and source reduction and reuse.

Energy Performance
Research on manufacturing process efficiency and heat recovery includes projects such as "Design and Demonstration of Multiport Cylinder Dryers," involving cylinder redesigns with the potential to increase the drying rate of paper by a factor of 2 over existing cylinder dryers. A pathway for fuel conversion and electricity production includes the project, "Characterization and Conditioning of Tars Produced During Black Liquor Gasification," which addresses one of the technology gaps identified by industry that is currently preventing the commercialization of black liquor gasification, and which could lead to a 10 percent energy improvement over the current combustion process. Research will examine black liquor gasification issues for its potential use in advanced turbines for on-site heat, steam and electrical power while reclaiming process chemicals. Other energy pathways will look at the environmental impact of energy production and utilization and provide the industry with optional methods in such areas as combustion, the wider use of renewable resources, and fuel production and enhancement. Research will be funded in FY 2000 in support of these research pathways.

Capital Effectiveness
This pathway involves research on materials and coatings, and lower-cost process alternatives. If successful, the project, Bleach Plant Capital Reduction with Rapid Bleaching and Simplified Stages," could result in significant savings on capital equipment and reduced discharge of chlorinated organic compounds.

Recycling
Research on the improved separation technology pathway includes the project, "The Removal of Wax and Stickies from Old Corrugated Containers." This effort will permit greater use of fiber obtained from recycled old corrugated containers by effectively removing wax and sticky contaminants during repulping and improving environmental, energy, and economics of the process. For the longer term, research is expected to include new technologies for sludge use and disposal, fiber-fiber bonding, and sorting and collection tools in addition to separation technologies.

Sensors and Controls
Research is undertaken on control devices, process measurement and diagnostics, process and product models, data presentation and interpretation, and control system effectiveness. The "Distributed Web Sensor for On-Line Measurement of Paper Basis Weight" is part of a multi-faceted effort to provide the paper industry with real-time techniques to monitor the entire moving paper web. Nuclear instrumentation will be distributed across the web width to detect beta particles transmitted by the web. The sensor for paper basis weight would improve product quality and productivity for the industry, and reduce its processing wastes. The research project, "Non-Contact Laser Acoustic Sensor for On-Line Measurement of Paper Stiffness," will use laser ultrasonics technology to improve paper uniformity, reduce the use of feedstock and production of waste, and increase energy efficiency, productivity, and paper quality.

Accomplishments. The Black Clawson Company commercialized a breakthrough cleaning technology for paper recycling. This new technology enables papermakers to use even lower grades of recycled paper without compromising the quality of the paper produced. This technology will assist the U.S. forest products industry in meeting its 2000 goal of recovering for recycling 50 percent of all the paper used. In addition, this improved cleaning technology achieves greater efficiency while using less energy. By 2010, it is estimated that the energy used for processing recycled paper will be reduced by 0.1 quads/year, with a corresponding annual CO_2 emissions decrease of 0.6 million tons. The research behind this technology involved a 45 percent industry cost share.

The American Forest and Paper Association (AF&PA) represents the industry—research alliances are underway among OIT, National Laboratories, private organizations, and academic institutions. Task groups established for each of the high-priority R&D areas are responsible for developing the pathways, requesting and evaluating proposals, and recommending research projects to DOE for cost-shared support.

Glass

Budget: FY98-$3.9M, FY99-$4.8M, FY00-$4.8M

Description, Objectives, and Performers. The glass industry produces 21 million tons of consumer goods annually valued at $22 billion. Glass making is highly energy-intensive consuming 170 trillion Btus in 1994, equal to about 15 percent of production costs. Theoretically, glass making requires 2.2 million Btus of energy to melt one ton of glass, but twice that amount is actually used because of inefficiencies and losses. Improvements in processing technologies have helped reduce energy consumption in glass making 25 percent in the last 15 years, and industry's goal is to reduce energy consumption by 50 percent (thus approaching the theoretical energy-use limits) by using more efficient technologies and processing operations, and increasing the use of recycled materials. The environmental impact of Glass making is relatively benign, however the direct carbon emissions from the glass industry are 2.96 MMTCE annually.

The industry is divided into four specialized areas: glass/glass packaging, flat glass, fiberglass, and specialty glass. Recognizing the need for research partnerships and advanced technologies to ensure its future viability, the industry signed a compact with DOE and produced its vision document in 1996, entitled "Glass: A Clear Vision for a Bright Future." More than 60 priorities for R& D were identified at a Glass Technology Roadmap Workshop the following year, based on their potential for saving energy, increasing productivity, and enhancing environmental performance during the glass making process, and on developing innovative uses for glass. A solicitation for proposals has generated more than 50 responses from interested researchers since the workshop, and the R&D collaboration is moving toward implementation.

In addition to reducing energy use 50 percent, goals of the vision document include reducing production costs at least 20 percent below 1995 levels, recovering and recycling 100 percent of consumer glass products in the manufacturing process, lowering air and water emissions a minimum of 20 percent, improving quality control during production, creating innovative products and broadening the marketplace, and increasing supplier-customer partnerships.

The Glass Packaging Institute is a trade association whose members are associated with the glass-container industry. However, there is no organization representing all four segments of the glass industry, and there has never been an organization that focused on technical issues affecting the industry. A Glass Manufacturers Industry Council (GMIC) is in the planning stages, which would serve as an umbrella association to track the industry's collaborative R&D efforts and increase the visibility of glass-related R&D.

R&D Challenges. Current sensors and control systems require significant advances in order to enable energy and cost reductions as well as better product control. In particular, systems must be integrated across the overall process and also improved for both specific and integrating process components in order to improve efficiency. Sensors better able to survive the temperatures and environments in the process are needed to enable real-time control. High temperature refractory and non-refractory materials, beyond those available today and

which do not affect product properties are also required. Lack of understanding of some fundamental process mechanisms influencing particulates also hinders progress..

R&D Activities. The roadmap calls for technological improvements in four areas: production efficiency, energy efficiency and conservation, environmental protection and recycling, and innovative uses for glass. Key priorities of the industry include development of refractory materials, optimization of oxygen fuel, and modeling of furnace operations.

Production Efficiency
The "High-Heat Transfer Low-NO_x Natural Gas Combustion System" will optimize the oxy-fuel system already being implemented by many companies for glass-melting processes. The system offers good heat transfer, increases energy efficiency 20 percent, and enhances process efficiency. The technology involves increasing the flame luminosity by seeding the flame with soot particles. The project partner is AccuTru International Corporation.

Energy Efficiency and Conservation
A "Sensor Technology Advanced Research" effort is underway that will be applicable in all four segments of the glass industry. The new sensor will provide more accuracy, reliability, and ability to withstand thermal shock, and will be long-lived, easily replaced, and interchangeable. Improvements in energy efficiency, product quality, waste minimization, and cost efficiency are expected. The research partner is AccuTru International Corporation.

Environmental Protection
"Glass Furnace Side Port Oxygen Enrichment" technology is being developed that will use a low-cost nitrogen oxide reduction technique on an industrial sideport furnace. (Sideport furnaces are used for 65 percent of U.S. glass production). The system reduces the amount of oxygen available to the flame's high-temperature zone, improves the flame temperature's uniformity, and improves heat transfer to the glass, without interrupting furnace operation or affecting product quality negatively. Several organizations are conducting this research, including the Institute of Gas Technology and Owens-Brockway Glass Container, Inc.

Innovative Uses of Glass
The "Advanced Microwave Processing Concepts" project is developing a Variable Frequency Microwave Furnace and demonstrating that microwave curing will reduce energy, lower costs, and increase production of certain new products such as resins, composites, and adhesives.

Accomplishments. The "Oxy-Fuel Firing,"or "Oxygen-Enriched Combustion System" for glass melting furnaces developed by Praxair, Inc. and OIT has been commercially successful. Companies adopting oxy-fuel firing in place of regenerative-type furnaces have reduced specific fuel use by 48 percent, NO_x emissions by about 70 percent, and particulate emissions by 60 percent, and increased their production rate by 25 percent. The quality of glass produced is more consistent, and furnaces converted to this type of combustion need to be replaced less frequently than regenerative systems. Over 20 percent of glass furnaces have converted.

"Advanced Optical Sortation," developed by Alpine Technology Inc., removes more than 90 percent of ceramic contaminants from waste glass (cullet), and allows glass to be sorted by color. Cullet melts at lower temperatures than virgin materials and provides the industry with energy savings of about 1 million Btus/ton annually. Nearly 100 percent of consumer glass may eventually be recovered with such technology, significantly reducing the environmental impact of such waste.

Chemical

Budget: FY98-$11.6M, FY99-$12.4M, FY00-$12.5M

Description, Objectives, and Performers. The chemical industry is the most diverse of U.S. industries, represented by about 10,000 corporations producing more than 70,000 different products that are classified under eight standard industrial classification codes, and which consume over 6 quads of energy. The products fall into three categories: (1) basic chemicals, (2) chemical products needed in manufacturing processes, and (3) finished chemical products that will be consumed or supplied to other industries. As the world's largest producer of chemicals, $372 billion worth of products were shipped worldwide in 1996, creating one of the largest trade surpluses of any industrial sector ($21.2 billion in 1996).

The industry prepared its vision statement, "Technology Vision 2020: The U.S. Chemical Industry," in 1996. Four technical disciplines were identified as crucial to the chemical industry: new chemical science and engineering technology, supply-chain management, information management systems, and manufacturing and operations. DOE research focuses principally on the first area.

The vision process involved the American Institute of Chemical Engineers, the American Chemical Society, the Chemical Manufacturers Association, The Council for Chemical Research, and the Synthetic Organic Chemical Manufacturers Association, as well as a significant number of companies and research organizations.

The size and complexity of the industry make it impractical to develop a single technology roadmap. To date, under new chemical science and engineering, 3 areas of the industry have been analyzed in depth, and roadmaps have been prepared for computational fluid dynamics (CFD), (1997); the separation technologies (adsorption, crystallization, distillation, extraction, membrane processes, and separative reactors), (1998); and computational chemistry, (1998). Roadmapping is underway for chemical process plant materials of construction, with emphasis on high temperature, corrosive-resistant materials, to be completed in early 1999. Additional areas of high industry priority are catalysis, chemical synthesis, separations for industrial biotechnology, electrotechnology and alternative reaction mechanisms, and chemical measurement. Catalysis impacts about 90 percent of the chemical industry's processes.

R&D Challenges. Current technologies limit the ability to control major processes to the degree needed for significant improvement. In addition, several types of separation technologies, such as distillation require considerable energy. Some processes involve the need for toxic solvents or involve such materials, and alternative feedstock and new processes could lead to major advances. New membranes and catalysts could lead to such advances and the ability to use alternative feedstocks. Advanced mathematical modeling, particularly for multi-phase flows, and better real-time controls along with advanced sensors could enable much of what is still today "art," become a much more highly and accurately controlled process.

R&D Activities. In February 1997, the Department signed a Memorandum of Understanding with the chemical industry for identifying appropriate areas for joint research with the focus on "New Chemical Sciences and Engineering" and the research areas described above.

Computational fluid dynamics (CFD) has become one of the more important engineering and analysis tools for the chemical industry over the past decade. As the result of many new developments, the predictive power of CFD for single-phase flow (for example, a single liquid) for process design and control is undisputed. The use of CFD for multi-phase flows (gas and solid together, for example) is far less well developed, however industry believes the potential value would be at least as great as single-phase flow CFD.

To achieve significant progress in the application of CFD to resolve difficult problems, such as flows in process equipment that cannot be seen, DOE has entered a partnership with seven DOE National Laboratories and industry for the development and commercialization of multi-phase CFD technology. A five-year development effort is envisioned.

Separations science and technology is becoming of increasing interest and importance to the chemical industry. Separations processes represent up to 70 percent of capital and operating costs and account for nearly 45 percent of the energy used in the chemical processing industries. The "Novel Catalytic Membrane Reactor," a source reduction technology being developed by the Department in collaboration with five major companies, will enter pilot-scale test and demonstration in 2000. This technology will minimize waste products while conducting highly exothermic reactions. Targeted applications include alkylations, carbonylations, hydrogenation, ethoxylations, and others. Current feasibility studies indicate that the Novel Reactor can achieve a twenty-fold improvement in the ratio of desired product to waste product compared to current technology. In addition to saving energy, reducing or eliminating waste disposal, and increasing product quality, the technology is also expected to increase yields and decrease the cost of raw materials.

Collaboration is underway between DOE's Office of Science and DOE's Office of Energy Efficiency and Renewable Energy in nearly a dozen Small Business Innovation Research projects for basic research in new and advanced membrane separation technologies. Two additional topic areas—reactive separations and alternative reaction conditions—are planned to be added.

In the electrochemical field, Los Alamos National Laboratory is performing research on the chemistry of chlor-alkali electrochemical reactors. These consume around 2 percent of the total electric power generated in the United States. The research could result in a new electrochemical reactor that reduces the total electric power consumption by the chlor-alkali industry by 30 percent and reduce CO_2 emissions from U.S. electric power generation by 0.6 percent.

In the catalysis field, the "Low Temperature, Aqueous Phase Catalytic Gasification" project has recently undergone a successful full-scale demonstration at the DuPont plant in Beaumont, Texas. The system is a catalytic process for destroying organic contaminants in industrial process streams and for producing clean water and a fuel gas. The process is an alternative to the deep-well injection of these wastes, and negotiations are underway between Battelle Memorial Institute and DuPont to optimize the application for future commercialization.

Accomplishments. The "Membrane Vapor Recovery System, VapoSep" for the recovery of VOCs from air was awarded the 34th Kirkpatrick Chemical Engineering Achievement Award, by the American Institute of Chemical Engineers in 1997. This membrane system is already becoming widely used in the chemical, petrochemical, and pharmaceutical industries.

The "Novel Membrane-based Process for Producing Lactate Esters" received high recognition during this past year as winner of the 1998 Discover Magazine Award for Technology of the Year, winner of the 1998 Green Chemistry Challenge Award, and winner of the 1997 Thiele Award for Engineering. Developed by Argonne National Laboratory in collaboration with NTEC, Inc., this technology is an entirely new process for the production of marketable nontoxic solvents. This process has the potential for replacing 80 percent of the 3.8 million tons of halogenated toxic solvents used annually in the United States with biomass-based solvents.

Mining

Budget: FY98-$0.0M, FY99-$2.0M, FY00-$3.0M

Description, Objectives, and Performers. Essentially all manufacturing starts with raw materials which must be mined. Mining (including hardrock and coal mining) occurs in all 50 States, contributing $39 billion per year in economic value. Mining operations consume almost 0.9 quads of energy annually and at the same time represent over 20 percent of the Nation's energy supply, including more than half of the energy used in electricity generation.

R&D Challenges. The key R&D challenges are being identified during the development of the industry technology roadmap.

R&D Activities. The mining industry developed a vision, "The Future Begins with Mining," and in May 1998, the National Mining Association signed a compact with DOE. In FY 1998 and FY 1999, technology roadmaps will be developed and priority technology needs identified. Research based on those roadmaps will be initiated based on competitions to be held in FY 1999 and FY 2000.

Accomplishments. As a new program start, accomplishments beyond the planning stage have not yet occurred.

Agriculture

Budget: FY98-$0.0M, FY99-$2.0M, FY00-$4.0M

Description, Objectives, and Performers. Agriculture represents about 14 percent of the U.S. GDP with exports worth $60 billion providing a trade surplus of $36 billion. The agriculture industry is extremely broad and diverse and has traditionally focused on producing wide varieties of food, feed, and fiber. Trees and plant matter have the potential to reduce fossil fuel consumption, as well as climate change effects, through their substitution for petroleum as feedstocks for producing products such as paints, plastics, and adhesives. These also provide additional markets for the agricultural industry, and it is believed that 0.35 quads of energy could be saved by 2020.

In 1995, a Memorandum of Understanding was signed by the Secretaries of DOE and the United States Department of Agriculture (USDA) to cooperate and coordinate technology research, development, transfer, utilization, and commercialization. The agriculture industry's first vision, "Plant/Crop-Based Renewable Resources 2020," was published in 1998, focusing on plant-based renewable resources as a long-range goal. A compact was signed by representatives of the U.S. agricultural, forestry, chemical communities, DOE, and USDA. This was the first time that this diverse set of American companies, nonprofit groups, trade associations, and academic institutions came together for a shared vision of the future for this emerging industry. The goal stated in the vision document is "to provide continued economic growth, healthy standards of living, and strong national security through the development of plant/crop-based renewable resources that are a viable alternative to the current dependence on non-renewable, diminishing fossil fuels."

The targets set in the vision document include:

- At least 10 percent of basic chemical building blocks to be derived from plant-based renewables by 2020 (a five-fold increase).
- Plant-based systems to produce renewable feedstocks with efficient conversion processes for selected products by 2020.
- Collaborative partnerships among industrial stakeholders, growers and producers, academia, and Federal and State governments to help develop commercial applications and revitalize rural areas.

R&D Challenges. While the overall technology roadmap is still under development, there is a need to identify genetic metabolisms and to be able to understand their pathways in order to effectively convert agricultural and forestry raw materials into chemical intermediates, in competition with hydrocarbons. To produce bio-based products, an understanding is required of how the fundamental properties of and variations in the agricultural raw materials relate to

the industrial process needs. Increasing the productivity of fermentors while reducing size, and increasing the efficiency of the separations process are also difficult technological steps.

R&D Activities. A primary barrier to using plant-based materials as feedstocks is the need to fit carbohydrate chemistry into processes based on hydrocarbons, that is, fossil fuels. Short-term R&D will call for modifying processes in order to economically use existing plant and crop materials. Longer-term R&D will apply recent advances in biotechnology to selected processing opportunities. Specific R&D goals are being developed in the technology roadmap to be completed this summer. A solicitation will be issued to select projects for FY 1999 funding based on the priorities identified in the roadmap.

Based on prior research (in the chemical program), a collaboration between ORNL, ANL, and industry is examining modifying *Escherichia coli* strands for the production of succinic acid from biomass. This could lead to an efficient biomass conversion process, reducing petrochemical feedstocks and energy, and sequestering CO_2 into commodity products.

Accomplishments. As a new program, accomplishments beyond the planning stage have not yet occurred.

Petroleum Refining

Budget: FY98-$3.0M, FY99-$0.0M, FY00-$1.0M

Description, Objectives, and Performers. The refining industry is the largest single industrial energy user, consuming 6 quads (over 25 percent of all manufacturing energy), but is also a major energy supplier vital to energy security. It also produces 180 million tons of waste and has the highest pollution abatement costs as a percent of sales, nearly 4 percent.

An initial phase of research was terminated in FY 1998 due to the industry's inability to reach consensus; prior research on catalytic cracking, fouling, combustion, and biodesulfurization have been, or are being, completed. Recent developments in the industry have led them to reconsider, however, and a vision document is expected in FY 1999. Future collaboration with DOE is expected based on direct and indirect energy efficiency technologies.

R&D Challenges. A new industry-developed vision and technology roadmap will identify the key technology needs and challenges.

R&D Activities. Prior activities have or are being completed while a new program will be initiated in FY 1999 and FY 2000.

Accomplishments. Accomplishments from the earlier program included major advances in fouling minimization in heat exchangers which have a significant effect on the energy efficiency of refineries. Equipment fouling is responsible for 0.2 quads of energy and $2 billion in operating and maintenance costs each year. Argonne National Laboratory has developed a methodology to predict fouling rates and threshold fouling conditions, thus improving operations. A high-temperature, high pressure fouling unit was also developed

and Argonne assisted two oil refining companies in mitigating fouling in hydrotreating and crude preheat units.

Crosscutting Technologies

Budget: FY98-$40.8M, FY99-$48.0M, FY00-$55.3M

Background

There are several enabling or supporting technology areas which have been identified as key or priority needs in multiple industry roadmaps. (Some, such as Advanced Turbine Systems and Combined Heat and Power for on-site industrial use, contribute directly to other strategic goals and are hence described under those goals.) The industry roadmaps have assessed future material needs; combustion processes, either for steam or heat or in the process itself; advanced sensors and controls, particularly real time measurements in hostile environments to improve process quality and productivity; and energy and environmental issues.

In addition, the vast number of factories and plants across the United States, operating diverse manufacturing processes and production systems, producing enormous numbers of materials and products, requires that an effective system be developed and utilized to ensure the rapid adoption of new technologies, advanced techniques, and best practices. Without integrating such approaches as part of an overall R&D results deployment system, many technologies are slow to be adopted and some wither. Small businesses and factories are particularly prone to being even unaware of the potential of energy efficient technologies and practices. By providing demonstrations of selected emerging technologies, showcasing and documenting advances and economic advantages that can be obtained, and developing and actively providing tools and information through collaborations with industry, stakeholders can accelerate the reduction in energy use and emissions, and reduce carbon emissions over the next decade which would otherwise be lost.

Linkage to CNES Goals and Objectives

The program is in direct support of CNES goal and objective:

- CNES Goal I, Objective 2 - Significantly increase energy efficiency in the transportation, industrial and buildings sectors by 2010.

The goal of the program is to produce a 25 percent improvement in energy efficiency and 30 percent reduction in emissions for the vision industries by 2020. The strategy to achieve this, in addition to focusing resources on the most energy and waste intensive industries, is to partner with and across industries, and align industry and government resources to areas of greatest need.

Program Description

Research and development is undertaken on critical crosscutting technologies, identified in multiple industry roadmaps, focusing on sensors and controls and combustion processes as well as on advanced industrial materials such as engineered ceramics, intermetallic alloys, and

membrane materials that have applications in many industries. Financial support is also provided, through competitive solicitations, to inventors and small businesses, and through State governments to local industries for developing inventions, innovations, and testing and demonstrating new technologies that emphasize applications to the Industries of the Future. Information dissemination, training, and showcasing advanced energy efficiency technologies help enable the completion of the development cycle and the continuing development by the private sector.

Enabling Technologies

Budget: FY98-$14.5M, FY99-$19.2M, FY00-$22.0M

Description, Objectives, and Performers. The technology base R&D, needed by multiple industries form the link to the more fundamental basic research supported by the DOE Office of Science. These enabling technologies also have relationships to R&D performed by FE and other DOE programs, and, at times, other agencies. Coordination of materials research is accomplished through the DOE Energy Materials Coordinating Committee (EMaCC) through the exchange of planning and budgetary information and through bimonthly technical meetings on selected topics involving DOE and major contractors. Department program managers also participate in information and coordination activities under the Materials Technology (MatTec) subcommittee of the National Science and Technology Council (NSTC) Committee on Civilian Industrial Technology. In addition, enabling technology results may be applicable to other industries beyond the Industries of the Future portfolio. Where the requirements are sufficiently defined and specific to a given industry, they are part of that industry's portfolio.

R&D Challenges. *Engineered Ceramics*
U.S. industry has a critical need for materials that are lightweight, strong, tough, corrosion resistant, and capable of performing at high temperatures. The availability of such materials will enable substantial increases in energy efficiency, reduction in emissions (such as NO_x, particulates, CO_2, and heat), and a decrease in life cycle costs. Advanced materials developed to date have not provided adequate durability and reliability for many key industrial applications. In the early 1990s, continuous fiber ceramic composites were at a very early stage of development and much too immature of a technology for industry to utilize. A study conducted by DOE concluded that investing in the development of these materials could provide substantial benefits to the U.S. industrial sector.

Advanced Industrial Materials
According to the National Materials Advisory Board, corrosion of metals in the United States costs about 4 percent of the gross domestic product. Using current methods of corrosion prevention on existing alloys could save about 15 percent of that cost, but development of new, corrosion resistant materials, particularly with high temperature fatigue resistance, could save even more. It is estimated that energy and production losses of 10 percent result from scheduled down time for maintenance and repair. Another huge energy consuming process is separations, predominantly done by distillation or cryogenic recrystallization. New, more robust, membrane materials for high temperature chemical separations could save at least half the energy currently used for separations by the U.S. industrial sector.

Combustion Technologies
Fossil fuel combustion in boilers, furnaces, and process heaters is still at much lower efficiencies than is possible and can be improved through better fundamental understanding, modeling techniques, and real-time sensing and control of both existing and additional variables, particularly on large scale units. Oscillating combustion requires additional understanding and development for applications beyond its initial use. Reduction of emissions and maximizing the use of multiple fuels also requires such advances.

Sensors and Controls
Most individual industry technology roadmaps have identified advanced sensors and controls as a critical element. It is surprising the number of major process steps that still rely on human operator experience and manual adjustment for process control, for want of capable and reliable sensors and the ability to directly measure (or indirectly infer) the necessary parameters under the high temperatures, harsh and corrosive climates, and high speed nature (e.g. rolling and paper mills) of many processes.

R&D Activities. *Engineered Ceramics*
In the area of advanced materials, engineered ceramics are being tested and developed for high temperature applications. For example, continuous fiber ceramic composite (CFCC) radiant burners will be tested in a glass plant and CFCC immersion tubes will be tested in an aluminum casting plant in 1999. Advanced industrial materials are focusing on advanced intermetallic alloys, with a new class of metal matrix. composites expected by FY 2000. CFCCs, in particular, have the potential for superior high temperature strength, and resistance to fatigue, corrosion, and wear. Research involves materials development and characterization, fabrication and joining techniques, long term testing in various corrosive environments and temperature regimes, and the development of testing methods and data bases to facilitate other technology and engineering development. In 1998, field testing was initiated at several industrial sites to evaluate CFCC radiant burner screens and immersion tube burners. In 1999, standards for use in design and testing will be published. The CFCC program involves collaboration between industry, National Laboratories and universities. The DOE laboratories, led by ORNL, are developing supporting technologies such as material design and processing methods and conducting performance evaluations. Five industry teams comprising 35 members (led by AlliedSignal Composites Inc., McDermott International, Inc., Dow Corning Corporation, General Electric Company, and Textron Inc.) are developing more than 20 applications.

Advanced Industrial Materials
The program concentrates on the development of selected new and improved materials to support critical industry roadmap needs, utilizing prior basic research from SC and elsewhere, and transferring the results to appropriate IOF industry programs for further technology development and demonstration. A major focus area is advanced intermetallic alloys, which have superior high temperature strength, corrosion resistance, and high temperature fatigue resistance. In FY 1998 and FY 1999, emphasis is shifting from nickel aluminide research to other intermetallic alloys, such as iron and titanium aluminides and a

variety of silicide alloys with potential for such uses as molten glass contact applications and corrosive atmospheres found in the chemical and refinery industries.

Continuing research includes methods of developing uniform spherical particles for the powder metallurgy industry and for spray coating metallic components with the intermetallic alloys. The Metals Processing Laboratory User Center (MPlus) at ORNL will be enhanced to support industry and university collaborative efforts. Since designation of the laboratory as a user center, more than 80 projects have been completed or are still active, with enthusiastic industrial response. The project for development of zeolite membranes for para-xylene separations and a project for development of electrochemical reactors for the chloralkali process have been transferred to the Chemical program for further development and demonstration. In FY 1998, the project to develop ultra-strong polymers by magnetic field synthesis will be completed, to be followed by demonstration by the Dow Chemical Company. By FY 2000, the development of a new class of metal matrix composites with superior strength and wear resistance will be completed, in cooperation with Reynold Metals Company and A.P. Green Industries.

Combustion Technologies
Essentially all process industries use combustion either in boilers, furnaces, or process heaters. Industry obtains 85 percent of its energy from the on-site combustion of fuels. In Combustion Technologies, vision and roadmap documents were developed along with long-term goals of improving energy efficiency (20-50 percent reduction in specific fuel consumption in furnaces); reducing emissions (2 ppm NO_x for boilers); maximizing the use of multiple fuels, including waste and renewable fuels; improving reliability (doubling the time between boiler outages); and reducing life cycle costs. Oscillating combustion technology for reducing energy use in steel reheat furnaces is being tested at Bethlehem Steel's Burns Harbor, Indiana, mill. Research is also planned for improved controls and sensors and increased systems integration. Coordination with SC, FE, and other offices is maintained through DOE's Combustion Coordination Group and interfaces are being established with SC's Combustion Strategic Simulation and Modeling activities.

Sensors and Controls
A need for improved sensors and controls has been identified in most of the technology roadmaps produced to date. There is a program goal to have, by 2009, significant advancements in the underlying science and technology of intelligent control systems. The initial focus of the program is on developing improved technology components in sensors, measuring instruments, information processing, and supervisory and communications systems. This focus will later shift toward advancing micro fabrication technologies and integrating components into smart, automated control systems to achieve improved throughput and productivity. Results will be customized and further developed for specific applications in the specific industry programs.

Accomplishments. Nickel aluminide research has been highly successful, with successful demonstrations in steel mill transfer rolls, commercialization as forging dies and heat treating furnace fixtures, and ongoing trials in more than 30 other applications.

Technical Assistance

Budget: FY98-$15.3M, FY99-$18.1M, FY00-$21.3M

Description, Objectives, and Performers. This program will bring the full range of OIT's technical assistance and technologies to thousands of plant sites in an integrated package that is easy for industrial partners to access. A recent, highly successful showcase at Bethlehem Steel's Burns Harbor, Indiana, plant demonstrated a large number of advanced energy-efficient technologies to representatives across the steel and other industries. Sub-divisions of this strategy include the Motor Challenge Program, that has already increased the use of advanced energy-efficient motors at the 3M Corporation; the Steam Challenge, as part of the Motor Challenge, to provide technical assistance on steam and compressed air systems; and the Industrial Assessment Center Program, that has pinpointed and analyzed opportunities in over 7,000 small manufacturing sites for saving energy, reducing pollution, and increasing productivity.

This approach will have an important role in launching new industrial technologies from the research and development stage to the manufacturing plant where the technology can be used to boost the productivity and competitiveness of U.S. industry. The goal of the program is to facilitate and promote the introduction to industry of near-term and emerging energy efficiency, renewable energy, and pollution prevention technologies.

Industry partners have requested a simpler, integrated package of industrial energy efficiency technologies, and technical and financial services—that is both flexible and easy to access. The strategy and implementation plans for this coordinated, integrated delivery approach will concentrate on outreach and technical assistance to IOF companies and plants, however the techniques and technologies are expected to spread across the spectrum of U.S. industry. In addition to deploying specific emerging technologies from the IOF R&D technology portfolio, technology resources are provided from several technical assistance programs.

R&D Challenges. The principal challenge is to enable the vast and diverse U.S. industry to have access to, valid data to assess, and the tools to evaluate, the multiple advanced energy efficiency technologies and techniques that are flowing through and emerging from the R&D pipeline in order to accelerate their adoption in pilot and full scale use.

R&D Activities. The Integrated Delivery Program has two main components:

Plant Utility Activities build upon the highly needed unbiased tools and information that assists plant-level energy efficiency decision-making. Tools such as the Motor Challenge Motor Master+ software, Steam Challenge 3E Plus Insulation software, Compressed Air Challenge Air Master, the Industrial Assessment Center (IAC) self assessment workbook, and the IAC database will be enhanced and delivered to industry through a variety of channels from trade and technical organizations (e.g., the Technical Association of the Pulp and Paper Industry, and the Association of Iron and Steel Engineers) to the Internet.

Technical Assistance Activities - the core of integrated delivery is the development of one-on-one partnerships with individual plants to showcase and adopt a broad spectrum of advanced

energy efficient technologies and techniques. The activities will build upon the successful collaborative showcasing of energy efficient steel production at Bethlehem Steel's Burns Harbor plant, where a spectrum of DOE developed technologies and techniques were shown in operation or through demonstrations and presentations to the rest of the industry and visitors from other industries.

Industry at all levels will be engaged in and exposed to the complete suite of IOF information, tools, and technologies that will help to implement clean, cost-effective strategies, while improving American industry's bottom line. An additional objective of the integrated delivery strategy is to provide a higher level of direct interaction and technical assistance with manufacturing plant personnel than ever before possible, and to positively influence the way energy, waste, and productivity decisions are made. As part of this system, and aimed at small companies and plants, are factory assessments performed by a network of trained university staff and students located around the country to provide evaluations and assistance at the local level.

The IOF Integrated Delivery strategy relies on the tools, services and technology resources of existing key program elements to offer technical assistance:

The *Motor Challenge Program* works in partnership with the electric supplier and controls industry to increase the market penetration of advanced energy efficient motor-driven systems. A key element in the Motor Challenge strategy is to encourage a "systems approach" to how motors, drives and motor-driven equipment are engineered, specified, purchased, and maintained by industry. Starting in FY 1999, and building on the success of the Motor Challenge program as a model, work was started to develop the tools and provide enhanced technical assistance, on steam and compressed air systems.

The *Industrial Assessment Center (IAC) Program* provides assessments to small manufacturers in order to pinpoint and analyze opportunities for cost-effective energy, waste, and productivity savings, and at the same time provides hands-on training to engineering students in energy, waste and productivity management practices. It is also the only program that provides engineering students with both theoretical and practical plant experience. This university-based program serves parts of 43 States through 30 university engineering departments.

Accomplishments. The Motor Challenge Program partnered with the 3M Corporation to optimize and upgrade electric motor systems at a 3M corporate campus facility. The combined savings from this systematic approach are more than $800,000 per year, and the project serves to promote these techniques and technologies to both other 3M plants and other companies.

The Industrial Assessment Center Program has provided industrial assessments to over 7,000 plants. At one plastic molding plant, an IAC team was able to make recommendations that, when implemented, cost-effectively saved the company approximately $134,000 per year, and significantly reduced the amount of waste plastic involved in the process.

Key partners include the 30 universities that currently deliver IAC assessments; numerous trade and professional societies; motor, controls, compressor and boiler manufacturers and distributors; and others that support the Motor Challenge, steam, and compressed air activities, and the IOF companies involved in showcasing and other efforts.

Financial Assistance

Budget: FY98-$11.0M, FY99-$10.7M, FY00-$12.0M

Description, Objectives, and Performers. OIT has traditionally relied on two separate financial assistance programs: (1) the Inventions and Innovation Program and, (2) the National Industrial Competitiveness through Energy, Environment, and Economics (NICE^3) Program. These programs were designed to speed the development of new energy efficient inventions, and to leverage industry and other resources to demonstrate and promote the benefits of advanced energy-efficient industrial technologies. The Inventions and Innovation Program provides "seed" support to private sector individuals and small businesses in the development of new energy efficient technologies. The program was recently re-engineered to be performed through competitive solicitations. The NICE^3 Program provides funding, on a competitive basis, to State and industry partnerships for projects that demonstrate energy efficient, clean production technologies that are emerging or ready for commercialization. In FY 2000, the Financial Assistance Program will provide an integrated delivery of these programs. In this way, selection of the most meritorious ideas and technologies is obtained through competition and an appropriate balance of the portfolio between short and long term technologies can be maintained.

R&D Challenges. These programs comprise competitively selected awards encompassing the entire industrial sector, but emphasize the Industries of the Future (IOF)—the R&D challenges encompass those identified in the collection of IOF technology roadmaps.

R&D Activities. In FY 2000, the Financial Assistance Program will use competitive solicitations for both the Inventions Program and NICE^3 that will, for the first time, be issued on concurrent schedules. The program will continue to provide opportunities for inventors, innovators, and entrepreneurs to help make their energy-related ideas a commercial reality and will also continue to offer (on a competitive basis) cost-shared funding to State and industry partners to demonstrate advances in near-term, energy efficient, and clean manufacturing technologies that are just becoming available for commercialization. By reducing DOE overhead activities, a larger total number of worthy projects can be supported. Also, the new program will better support and target IOF sectors by using competitive solicitations that are designed to encourage and favor participation by energy and waste intensive industrial sectors. The impact of the new program will also be improved by working with regional centers to more effectively leverage local resources, and to better tailor assistance to specific regional/local needs and situations.

Accomplishments. A grant from the Inventions and Innovation Program provided the Helysis Corporation $70,000 to help develop a new technology that would permit the automated production of mold or die blocks in less time, at competitive energy usage, and at lower cost than traditional methods. The new process involved a patented system called

Laminated Object Manufacturing (LOM). Currently, LOM systems are operating in large corporations such as General Motors, Chrysler Corporation and Ford Motor Company, as well as in small pattern makers, government agencies and universities in more than 26 countries around the world.

With the help of a competitive NICE[3] grant, Whyco Technologies, Inc. developed a new plating technology. The Whyco technology uses 15 percent less energy, eliminates more than 255 tons of solid waste per year, and reduces waste water by more than 17,000 gallons per day—resulting in cost savings of more than $500,000 annually. The company has manufactured and sold more than 175 of these systems to other electroplating companies, which are reporting up to a 40 percent increase in plating productivity.

Summary Budget Table (000$)

Clean and Productive Industries Research Areas	FY 1998 Appropriated	FY 1999 Appropriated	FY 2000 Request
Industries of the Future	**53,080**	**57,460**	**74,020**
Aluminum	7,340	8,100	11,180
Steel	9,730	10,530	10,630
Metal Casting	5,480	5,740	5,800
Forest Products	12,040	11,960	21,080
Glass	3,880	4,790	4,830
Chemical	11,610	12,380	12,500
Mining	0	1,980	3,000
Agriculture	0	1,980	4,000
Petroleum Refining	3,000	0	1,000
Crosscutting Technologies	**40,770**	**48,020**	**55,300**
Enabling Technologies	14,470	19,220	22,000
Technical Assistance	15,340	18,100	21,300
Financial Assistance	10,960	10,700	12,000
Total	**93,850**	**105,480**	**129,320**