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ENHANCING THE COMPETITIVENESS,

EFFICIENCY, AND ENVIRONMENTAL

QUALITY OF AMERICAN INDUSTRY

THROUGH TECHNOLOGY PARTNERSHIPS

U.S.
Department
of Energy

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U.S. DEPARTMENT OF ENERGY

OFFICE OF ENERGY EFFICIENCY
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Department of Energy

Washington, DC 20585

February 1997

To Our Readers:

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

A critical component of the Federal Government's effort to stimulate improved industrial energy efficiency is the Department of Energy's (DOE's) Office of Industrial Technologies (OIT). OIT funds research, development, and demonstration (RD&D) efforts — usually on a cost-shared or cooperative basis with industry partners — and uses a wide range of channels to transfer the resulting technology and knowledge to industry.

Located within DOE's Office of Energy Efficiency and Renewable Energy (EE), OIT is the principal organization in DOE responsible for the development and transfer of advanced technology to basic industries in the United States. OIT promotes industrial competitiveness and enhanced environmental performance by improving the energy and materials efficiency of industrial processes. It also supports the development of technologies that can contribute to thousands of new jobs, higher wages, increased exports, and improved profits.

This document describes OIT's program and provides in one place much of the information that we believe our customers want to know about our program. It describes OIT's important, new customer-oriented Industries of the Future (IOF) initiative and the strategic visioning and technology roadmapping activities that are part of the IOF process. It also describes the energy, economic, and environmental characteristics of OIT's principal customers — the materials and process industries — that consume nearly 80% of all energy used by manufacturing in the United States. OIT-supported RD&D activities relating to these industries are described as well, and quantitative estimates of the potential benefits (or metrics) of many current OIT-supported technologies for U.S. industry are also provided.

This report is an outgrowth of OIT's evolution to a customer-focused organization — one that strives to continuously improve the quality of its products and services and the satisfaction of its customers. It is part of our continuing dialogue with our customers about their needs, the extent to which our products and services meet those needs, and how we can improve our products and services in the future.

In keeping with our customer-focused philosophy, we invite your comments or questions about any aspect of this report or the OIT program; contact points are listed on the inside back cover of this report.

A handwritten signature in cursive script, reading "Denise F. Swink".

Denise F. Swink
Deputy Assistant Secretary
for Industrial Technologies
Office of Energy Efficiency and Renewable Energy

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THE OFFICE OF INDUSTRIAL TECHNOLOGIES: AN OVERVIEW

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WHAT OIT DOES

Industries of the Future: Putting the Customer First

A close working relationship with industry, professional societies, and similar groups has been an OIT tradition since the organization was formed 20 years ago. However, to further strengthen its bonds with its industrial customers, OIT recently undertook a major initiative called Industries of the Future. IOF puts the customer first.

In the Industries of the Future process, OIT acts in a role that government is uniquely able to play. OIT encourages collaboration among the most energy intensive industries and facilitates a process in which they develop for themselves a strategic vision of their desired future, and a "technology roadmap" to help achieve their vision. This process enables each industry to identify and prioritize its collective technology needs.

The identification of the critical technology needs of industry, in turn, enables OIT and other Government R&D providers to focus their limited funding and other resources in the most important areas. The identification of the critical technology needs of industry also helps promote leveraging of scarce public and private sector R&D resources.

In keeping with its energy efficiency mission, OIT concentrates on the most energy intensive industries because those industries offer the best opportunities for improved energy efficiency. These include the chemical, petroleum refining, forest and paper products, steel, aluminum, metal casting, and glass industries.

R&D Support

A key aspect of OIT's program is to provide R&D funding support to improve the resource efficiency of these energy intensive and environmentally sensitive industries. OIT co-invests in promising research areas where the cost or risk is too high for individual firms to assume alone.

Industrial leadership in identifying technology needs helps pave the way for cost-shared R&D partnerships with the private sector. Industry cost-sharing helps ensure industry's commitment to the research and enhances the probability of commercialization.

OIT also provides its industrial customers with simplified access to the vast science and technology resources of the National Labs and other parts of DOE.

OIT funds R&D to help reduce raw material and depletable energy use and reduce the generation of waste and pollutants. OIT funds R&D that helps shift industrial investment toward

improvements in resource productivity and away from nonproductive pollution abatement and control measures.

Two of the most important mechanisms available for industrial participation in OIT R&D funding programs are (1) cost-shared financial assistance awards and cooperative agreements, and (2) cooperative research and development agreements (CRADAs). These mechanisms are described in greater detail on page 17.

Technology Access and Deployment

In addition to cofunding R&D, OIT also sponsors low-cost, high-impact technology transfer and information dissemination programs for deploying best-practice and emerging technologies. In this role, OIT works closely with industry trade associations and technical societies, sponsors technical workshops, and cooperates with state and local governments.

OIT's array of technology access programs, activities, and partnerships helps overcome barriers to market acceptance of new, energy-efficient, environmentally friendly, competitiveness-enhancing technologies. In shaping its portfolio of programs and activities, OIT has carefully selected industry target groups and designed program techniques appropriate to their needs:

- Manufacturers using electric motors – information support (Motor Challenge)
- Small and medium-size manufacturers – plant assessments and productivity recommendations for energy and waste savings (Industrial Assessment Centers)
- Firms needing technology demonstration – grants and involvement of state energy offices through their sponsorship (NICE³ grants)
- Industrial companies – voluntary commitments to reduce greenhouse gas emissions, and recognition and support for their actions (Climate Wise)
- Inventors of promising technologies for energy supply, energy savings, and pollution reduction – commercialization guidance (Inventions and Innovations)
- Industry wide – alerting companies to potential opportunities from technologies applied in other industries (Technology transfer)

OIT also sponsors the national Industrial Energy Efficiency Symposium and Expo to promote more productive interactions among the vast community of industrial technology developers, suppliers, and users. These activities are described briefly below and in greater detail in Part 5 of this report.

THE FEDERAL ROLE IN INDUSTRIAL R&D

"As the U.S. continues to face increased international competition, it will become increasingly important to better utilize R&D resources through a broad range of collaborative activities. Individual companies will find it increasingly difficult to obtain sustainable competitive advantage. In a global marketplace, the U.S. steel industry must strive to maintain its competitive position through collaboration. Such effort will leverage the resources and research capabilities of individual companies, provide a closer link between private and public research, and ultimately insure a greater return to society on these investments. Successful collaboration... will maintain the strength and vitality of an important manufacturing sector."

"Steel — A National Resource for the Future," a joint report of the American Iron and Steel Institute and the Steel Manufacturers Association, May 1995.

"The increasingly competitive business environment facing American industries will limit the ability of private industry to finance as much long-term research as it has in the past. Thus, partnerships with federal agencies and research institutions, academia and other industrial firms will be increasingly important to facilitate these future advancements."

"Glass — A Clear Vision for a Bright Future," from the Glass Industry Technology and Vision and Research Agenda, January 1996.

Recent Trends in Industrial R&D

Despite a prosperous economy and booming stock market, R&D spending in the United States has remained relatively flat in constant-dollar terms for several years. Since 1987 the economy in real terms has grown 2.24% annually while constant-dollar R&D expenditures by U.S. industry have increased at only about a 0.65% rate.

Moreover, a recent survey has shown how private sector R&D efforts are increasingly being directed at short-term product development at the expense of more costly, higher risk but potentially more rewarding medium- and long-term R&D. A survey by the National Science Foundation indicated that in 1991 basic research

accounted for 7.8% of all industrial R&D and applied research accounted for 24%. By 1995, these figures had changed to about 7.4% and 22%, respectively.

Private sector cutbacks in high-risk, medium-term research have been driven by competitive pressures to downsize, streamline, move technology closer to the customer, reduce costs, and improve quality. The short time horizons of investors and lack of patient capital have also contributed.

Indeed, the prestigious Yergin Task Force report titled "Energy R&D: Shaping Our Nation's Future in a Competitive World" in June 1995 observed that the focusing of corporate R&D expenditures on projects with short-term goals and quick payback is a response to corporate restructuring and financial market pressures.

A result of this trend is that longer term, higher risk, more uncertain projects are less likely to be undertaken in the private sector. This emerging gap in the funding of medium- and long-term R&D threatens to limit the future stock of innovative technology U.S. industries will need to remain competitive and environmentally sound.

Behind the Need for Public-Private R&D Partnerships

Such corporate belt-tightening has contributed to a growing need to leverage external R&D resources. With private sector R&D budgets cut and refocused toward near-term results, cost-sharing with Federal agencies enables companies to explore innovative technology options that otherwise would be screened out, and to do so with a longer time horizon. Such R&D partnering has a positive side effect as well: It enables industry to have more input to defining the future directions of Federal R&D.

Figure 1-1. U.S. R&D Expenditures by Source of Funds

Source: Scientific and Engineering Indicators 1996, National Science Board

THE FEDERAL ROLE IN INDUSTRIAL R&D

Figure 1-2. Trends in Industry R&D Spending by Category, 1991-1995

Source: *Scientific and Engineering Indicators 1996*, National Science Board

Growing pressure to limit the growth or even reduce the overall levels of Federal R&D spending is also driving the creation of R&D partnerships between government and industry. Prospects for flat or declining Government R&D funding is pushing the Government to better sharpen its R&D priorities. It is becoming more important than ever that the limited amount of Federal funding allocated to industrial R&D is aligned with the pre-competitive, medium-term R&D needs of the private sector.

But high costs and risk and funding cutbacks are not the only factors behind the increase in cooperative R&D activities between industry and government. Technology is complex and often emerges from a variety of sources. It is becoming increasingly difficult for individual firms to keep up with the rapidly and constantly expanding frontiers of technology. Thus, the proliferating level and sources of technological knowledge are also driving the increase in collaborative efforts.

OIT's Role: Help Keep Basic Industry Technologically Competitive

The Yergin study concluded that Federal support of energy-related R&D addresses key challenges not being met by the private sector. In particular, government investments are valuable when technical and commercial risks are high and when the innovation has a substantial potential public benefit but would not yield adequate returns to the private investor.

Many promising fundamental improvements in the energy and capital intensive and environmentally sensitive industries that are OIT's principal customers are simply too expensive and too risky for individual private firms to pursue by themselves — particularly when innovative, first-of-its-kind concepts are involved.

Hence, while there are appropriate limits to government support of new technologies, organizations like OIT have an essential role to play in helping to keep U.S. basic industries technologically competitive. In the absence of private sector investment, OIT cost-sharing can lower the risk and cost of technology development to a level more acceptable to private sector partners.

OIT acts as a catalyst in drawing together many firms with National Laboratories, universities, institutes, and other interested parties to pool risk, investment, and know-how in expensive, high-risk but promising technologies. The mechanism OIT uses to partner with industry and align its limited R&D funding with the needs of its industrial partners is called the Industries of the Future (IOF) process. IOF is described in greater detail on the following pages.

"Federal Policy should put particular emphasis on fostering high-yield partnerships with the private sector and universities."

"Endless Frontiers, Limited Resources," Council on Competitiveness, April 1996.

OIT AND THE INDUSTRIES OF THE FUTURE PROCESS

"There is a very positive government program that directly affects the pulp and paper industry. Specifically, it's DOE's Industries of the Future program... DOE is working with various energy intensive industries to create master research plans. The research will help these industries improve energy efficiency and reach other technological goals.... This isn't a top-down, we know what's best for you government project. It is a true government-industry partnership.... This project shows how government programs ought to work. With Industries of the Future, DOE is funding pre-competitive research that individual companies might be reluctant to do on their own.... It is seed money to stimulate future technological and economic growth...."

From editorial by Alan Rooks, Editor-in-Chief, *Paper Industry Management Association Magazine*, December 1995.

Aligning Federal R&D with Industry's Needs

OIT's Industries of the Future process encourages industries to identify their collective high-risk, high-payoff technology needs. This, in turn, allows OIT, DOE, and other Federal R&D organizations to align their resources to best meet those needs where appropriate.

The IOF process provides a basis for coordinated technology planning in which gaps and areas of potential collaboration with existing programs are identified by teams of experts from the private and public sectors.

OIT's Industries of the Future initiative is helping to create new communications channels within and across industries and between industry and government. It is also helping to accelerate the development, dissemination, and use of innovative technology and process improvement solutions. The IOF process also

- Helps identify leverage points by providing a means for matching national capabilities with technology needs and establishing RD&D partnerships between industry and government participants
- Encourages more coordinated efforts by firms, universities, States, and Federal agencies

- Enables more coordinated and carefully focused government support of industrial technology and fosters intra- and interagency alliances within government
- Simplifies and streamlines the process of working with government, including the contracting and procurement processes
- Stimulates the development and use of technologies that increase energy efficiency and lower the costs of environmental protection and regulatory compliance in industry
- Makes it easier for industry to penetrate the maze of programs at the DOE National Labs, enables more effective use of the system's specialized and often very high-level technological capabilities, and helps focus the competencies of the DOE and other Federal labs on industrial applications

Industry Leads the Industries of the Future Process...

...defines the goals and objectives, and sets the technology priorities. It also identifies and tasks the key participants, including suppliers and users who are critical to the success of the process. Industry commits resources to the IOF process, conducts R&D, assesses progress against goals, and uses the results. To ensure success of IOF, industry provides senior-level commitment and industry champions to the overall process.

OIT Acts as a Facilitator...

...for the Industries of the Future process. In this role, it acts as a catalyst for key industry, government, and other interested participants as they conduct integrated technology planning. OIT is ideally suited for the role of catalyst and facilitator for the IOF process. As the primary Federal interface with the Nation's materials and process industries, OIT has developed in-depth knowledge of these industries' cultures and concerns, as well as many long-term relationships with industry leaders and organizations. OIT also

- Helps coordinate the input of the many stakeholders
- Assists in the planning and may provide draft portions of technology roadmaps
- Acts as a focal point for industry in identifying other government resources of potential interest to the industry
- Provides cost-sharing to many R&D projects identified by the IOF process

OIT AND THE INDUSTRIES OF THE FUTURE PROCESS

- Provides third-party objectivity
- Enables things to get done that could not get done before

IOF Participants

Private sector participants in the program include industrial companies and trade associations, universities, private research institutions, and environmental and public-interest groups. Government participants — in addition to OIT and other DOE groups such as Fossil Energy, Energy Research, Defense Programs, Environmental Management, and the DOE labs — may include the Environmental Protection Agency, the National Institute of Standards and Technology, the National Science Foundation, the Department of Agriculture, State agencies, and others as appropriate.

Value of IOF to Industry

IOF increases industry's R&D leverage and allows industry to align and integrate the full range of industry participants into the process.

It enables industry to capitalize better on existing research being performed at DOE, the National Labs, government agencies, and other organizations.

And, it facilitates the creation of R&D partnerships that help focus limited technical resources and mitigate the inherent technical, commercial, and financial risk of these activities.

Value of IOF to Government

The IOF process enables Government to better focus on and increase its responsiveness to its customers.

By involving private sector interests early on in the R&D planning process, it helps increase the likelihood of a positive return on government's limited funding available for R&D investments.

The communications links between industry and government that are forged by the IOF process improve the ability of DOE's National Labs to leverage the historical investment that has been made in them.

INDUSTRIES OF THE FUTURE: FOCUS ON SEVEN ENERGY INTENSIVE INDUSTRIES

Figure 1-3. Estimated Manufacturing Energy Use by Industry, 1994 (end-use basis)

Source: EIA

OIT's core strategy focuses on seven basic industries. These industries — commonly referred to as the materials and process industries — include the chemical, petroleum refining, forest products, steel, aluminum, metal casting, and glass industries.

Despite the great size and complexity of the industrial sector, by themselves these seven industries account for about 80% of the manufacturing sector's end-use energy (Figure 1-3).

In addition to high energy intensity, these industries share other prominent characteristics:

- They account for over 80% of the volume of all waste and pollution generated in manufacturing and about two-thirds of all pollution control expenditures in manufacturing.
- Collectively they employ about 2.9 million workers whose hourly wages exceed those of manufacturing overall by about 12% and are 86% more than those of the average retail worker (Figure 1-6).
- They account for about one-seventh of all U.S. merchandise trade and their continued competitiveness is an essential factor in the competitiveness of all U.S. industry.

Figure 1-4. Manufacturing Pollution Abatement Costs by Industry

Source: Bureau of the Census

The Seven Industries of the Future are:

- Chemical
- Petroleum refining
- Forest products
- Steel
- Aluminum
- Metal Casting
- Glass

INDUSTRIES OF THE FUTURE: FOCUS ON SEVEN ENERGY INTENSIVE INDUSTRIES

- They directly account for about 5% of U.S. gross domestic product (Figure 1-5).
- With the exception of the chemical industry, their R&D expenditures are about two-thirds below the average for all manufacturing (Figure 1-7).
- They are indispensable links between such natural resource industries as farming, forestry, mining, and oil and gas extraction and such value-adding assembly industries as automobiles, aerospace, construction, and electronics.
- Their continued health and robustness are critical to the maintenance of a sound national defense posture.

Figure 1-5. Materials and Process Industries, Share of GDP

Sources: Department of Commerce; DIT estimates from Department of Commerce data

Figure 1-6. Wages in the Materials and Process Industries Compared to Those in Other Industries

Sources: 1994 Annual Survey of Manufactures, Bureau of the Census; Statistical Abstract of the United States 1995 (Table #668)

Figure 1-7. R&D Expenditures in the Materials and Process Industries

Sources: Research and Development in Industry: 1994, National Science Foundation; 1994 Annual Survey of Manufactures, Bureau of the Census

INDUSTRIES OF THE FUTURE: INDUSTRY VISIONS

"Each industry collectively defines what it wants to look like in the future, and identifies what it needs to do — in both technology and non-technology areas — to get there."

Denise Swink, Deputy Assistant Secretary — Industrial Technologies, DOE.

Industry Visions

An **industry vision** is an industry-defined view of its desired future and a long-term strategy to attain it. It is developed by industry for industry.

It enables **an entire industry** to address its major challenges and opportunities. For example:

The American Forest and Paper Association, supported by NCASI, RPTA, FPS, and The Association of the Pulp and Paper Industry, has been identifying the major long-term technological needs and challenges that could have significant impact on the industry 20-30 years in the future.... The process of developing the industry's technology vision and research agenda has been led by a CEO level working group headed by the chairman of AF&PA and composed of CEOs representing the full range of industry products and interests.... The AF&PA is the national trade association of the forest, pulp, paperboard, and wood products industry. AF&PA represents approximately 425 member companies and related trade associations (whose memberships are in the thousands) which grow, harvest, and process wood and wood fiber; manufacture pulp, paper and paperboard products from both virgin and recovered fiber; and produce solid wood products.

From "Agenda 2020 — A Technology Vision and Research Agenda for America's Forest, Wood and Paper Industry," November 1994.

Situation Analysis

The vision provides a **situation analysis of the industry** and identifies the principal market, business, and societal drivers impacting the future of the industry. Consider, for example, an excerpt from the aluminum industry vision:

Although several of the key drivers may influence each of the three aluminum industry sectors, each possesses unique scientific and technical needs.

The Raw Materials Sector is characterized by relatively established underlying processes, and RD&E for this part of the industry is likely to focus on reducing costs via improved operations, energy and environmental efficiencies.

The Semifabricated Sector will likely focus on lowering costs and improving performance, quality and environmental acceptability via the development and application of advanced manufacturing processes and technologies.

In the Finished Product Sector, the opportunity may hinge on increased integration of materials and on enhanced process, product design, and enabling technologies to create the products 21st century consumers will demand.

From "Aluminum — Industry-Government Partnerships for the Future," March 1996.

Major Challenges and Barriers

The vision also identifies the **major challenges and barriers** facing the industry. For example, the steel industry identified the following challenges in its strategic vision:

- *Competition from imports... worldwide may continue to have a negative impact on the industry....*
- *Overcapacity has been an enduring feature of the world steel industry... averaging 25% over the past 20 years....*
- *The pressure to improve environmental performance will remain a competitive challenge....*
- *The steel industry will remain energy- and resource-intensive and vulnerable to volatile energy prices....*
- *Pressures to reduce solid wastes, maximize utilization of resources and increase recycling will also factor in....*
- *Demands of customers and the constant drive for improved quality will continue to have a dramatic impact....*
- *Competing materials will threaten steel in important markets....*

From "Steel — A National Resource for the Future," May 1995.

INDUSTRIES OF THE FUTURE: INDUSTRY VISIONS

Technology Objectives and Performance Targets

An industry vision sets **strategic technology objectives and performance targets**. For example, to remain vigorous and competitive, the glass industry identified the following goals:

- *Operate with production costs at least 20% below 1995 levels....*
- *Recycle 100% of all glass products in the manufacturing process....*
- *Reduce process energy use... by 50%....*
- *Reduce air/water emissions by a minimum of 20%....*
- *Recover, recycle and minimize 100% of available post-consumer glass....*
- *Achieve six sigma quality....*

From "Glass — A Clear Vision for a Bright Future," January 1996.

Likewise, the metal casting industry, in its strategic technology vision, cited the following objectives, among others:

- *Increase market development activities to improve market share by 10% and recapture 25-30% of lost markets....*
- *Develop advanced manufacturing technologies to increase productivity 15%, reduce lead times 50%, and reduce energy consumption 3-5%....*
- *Develop environmental technologies to achieve 100% pre- and post-consumer recycling....*

From "Beyond 2000 — A Vision for the American Metal Casting Industry," September 1995.

Identification of Strategic Technologies

The vision provides a framework for **identifying strategic technologies required to make the vision possible** — technologies that offer exceptional potential for improving competitiveness, resource efficiency, and environmental protection. For example, the steel industry in its vision cited 15 immediate and longer term R&D priorities, including the following:

- *Commercialization of cleaner, energy-efficient, alternate ironmaking processes;*
- *Commercialization of processes to recycle in-plant wastes;*
- *Improved iron units for EAF and BOF charge;*
- *Develop new flexible steelmaking processes that can optimize sources of iron units and energy;*
- *Develop a totally continuous steel production process.*

From "Steel — A National Resource for the Future," May 1995.

In summary, the technology visions outline key strategies for success and are an integral component of the IOF approach to doing collaborative work with industry. The strategies are developed in greater detail in the industry roadmaps, as discussed on the next page.

The Compact

Typically, after each industry completes its vision, it enters into a formal compact with the Department of Energy. **The compact is an agreement that lays the foundation for collaborative efforts between industry and the Federal Government.**

Signed by both key industry spokesmen and the Secretary of Energy, it is a formal commitment to align DOE's limited resources to meet the challenges identified in the vision.

The compact is a voluntary collaborative effort between an industry and DOE to help ensure the long-term technical and competitive viability of the industry.

It paves the way for collaborative R&D and information dissemination projects and provides industry with streamlined access to the National Labs and other DOE resources.

INDUSTRIES OF THE FUTURE: TECHNOLOGY ROADMAPS

"Roadmaps" Help Clarify Technology Needs and Options

After each industry prepares its vision and signs the compact with DOE, plans are initiated to develop a technology roadmap that sets milestones for achieving the goals articulated in the strategic vision. The roadmap identifies current technologies and barriers, options and pathways. It lists technical requirements and targets, sets technology priorities, and establishes the research agenda.

The roadmap establishes industry's portfolio of near-, medium-, and long-term technology research, development, and deployment activities to address the challenges and opportunities identified in the strategic vision document.

While OIT typically assists in the development of the roadmap by providing support to many activities, the roadmap is an industry-driven process that is facilitated by OIT and not the reverse.

The Roadmapping Process

The industry solicits the participation of key individuals to help plan the roadmapping process. These individuals typically represent a broad cross-section of experience and knowledge of the specific industry. The group works with OIT to prepare an outline of the roadmap and to define a process for completing it. If needed, OIT can provide support to help draft a sample roadmap, facilitate meetings and workshops, and convert the meeting recommendations into an action plan.

If required, early in the process OIT coordinates the meeting of legal counsels representing industry associations. This helps establish procedural guidelines to ensure compliance with all antitrust requirements and the protection of individual company intellectual rights and properties. Appropriate steps are also taken to avoid procedural obstacles for the technology roadmapping process. A series of facilitated technical workshops are then

held to specify the technology pathways for the roadmap and set research goals. Participation is open to as many interested parties as may be accommodated. The proceedings of the workshops are recorded and then integrated into a draft technology roadmap. Review of the draft document is then often coordinated by an industry trade association or similar group.

OIT hosts meetings with government research agencies that may be willing to participate in the implementation of selected segments of the technology roadmap. The goal is to leverage OIT's funding and to develop industry support in Federal Government areas that are outside of OIT's mission but of potential application to industry.

The draft technology roadmap is presented to the general scientific public for critique and comment at major industry and professional society meetings, exhibitions, and conferences. Comments from these forums may be incorporated into the final document. Such reviews satisfy DOE's requirements for public disclosure and participation in the generation of government-supported planning documents for future industry-government R&D partnerships.

Figure 1-8. Sample Roadmap for One Focus Area (Generic)

HOW OIT HELPS: EXPO

In order to provide a forum for government and industry to discuss strategies for working together to meet resource efficiency goals, OIT sponsored its first Industrial Energy Efficiency Symposium & Exposition (Expo).

Held at the Renaissance Hotel in Washington, DC, on May 1-3, 1995, the theme of Expo was "Investing in a Cleaner, More Productive Economy." Expo drew nearly 700 participants and 102 exhibitors representing DOE's National Labs and the seven industries that are OIT's principal customers.

The three-day conference examined industrial energy, and economic and environmental policy issues in a rich variety of sessions, workshops, and exhibits. Expo brought together manufacturers, suppliers, customers, research laboratories, universities, and government program managers. It facilitated networking and the exploration of research and technology alliance opportunities. Expo created an environment in which to

- Take advantage of new market opportunities
- Explore innovative ways to accomplish national objectives through cooperative programs and teaming arrangements

Keynote speakers such as Secretary of Energy Hazel O'Leary and Congressman Vernon Ehlers (R-MI), Vice Chair of the House Science Committee, addressed how to accomplish national objectives through cooperative programs and teaming arrangements.

Many attendees predicted new business as a result of contacts made at the event, and participant feedback was overwhelmingly positive. For example, Richard Biljetina, Vice President of the Institute for Gas Technology (IGT), said: "We found the symposium and expo provided an excellent opportunity to talk with a number of potential manufacturing partners for some of our new technology concepts under development at IGT."

The American Council for an Energy Efficient Economy said: "It fostered greater cooperation among industries, government, researchers and public interest organizations."

Strong Congressional support was voiced for the advancements being made in industrial energy efficiency as well as new technologies already in use as a result of partnering. For example, Congressman Ehlers said: "There is real value to partnering with DOE. The long-term depletion of

energy resources is our real crisis and the right approach is to concentrate on energy efficiency."

Indeed, the success of Expo was such that a second one has been planned. The 2nd Industrial Energy Efficiency Symposium & Expo will be centered around a theme of "Turning Industry Visions into Reality." Whereas the agenda for the first Expo was facilitated by OIT, the agenda for Expo II has been developed and facilitated by industry. Despite the unexpectedly large number of requests for space, the number of exhibitors has been limited to 100.

Expo II is designed to meet the needs of

- Business managers responsible for shaping R&D trends
- Federal program managers involved with U.S. industry
- Congressional members and their staff concerned about U.S. competitiveness
- Technology managers evaluating future trends in U.S. industry
- Policymakers seeking to improve industry and government interaction

Expo II will be held at the Hyatt Regency Crystal City in Arlington, VA, February 24-26, 1997. Additional information can be obtained by faxing your request to 301-621-3329 or contacting OIT at <http://www.oit.doe.gov>.

2nd INDUSTRIAL ENERGY EFFICIENCY SYMPOSIUM & EXPO

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OFFICE OF INDUSTRIAL TECHNOLOGIES

HOW OIT HELPS: IMPROVED ACCESS TO DOE'S NATIONAL LABS

The Lab Coordinating Council

Because the Industry of the Future process prompted a number of requests concerning the capabilities of DOE's National Laboratories and Facilities, a Laboratory Coordinating Council (LCC) was established. The Council's member organizations include

- Ames Lab
- Argonne National Lab
- Brookhaven National Lab
- Idaho National Engineering Lab
- Kansas City Plant
- Lawrence Berkeley National Lab
- Lawrence Livermore National Lab
- Los Alamos National Lab
- Morgantown Energy Technology Center
- National Renewable Energy Lab
- Oak Ridge National Lab
- Pacific Northwest National Lab
- Pittsburgh Energy Technology Center
- Savannah River Technology Center
- Sandia National Lab
- The Y-12 Plant

The LCC can provide industry with information that expedites access to the vast science and technology capabilities and expertise of the National Labs and facilities. The LCC also facilitates collaboration between the Labs and industry and can assist in matching industrial technology needs with the appropriate capabilities and assets of the National Lab system.

The Council meets on a regular basis to discuss with DOE and industry representatives methods that can make the interaction more productive. For the forest products industry, as an example, the Council has put into place a subcommittee structure that parallels the AF&PA Agenda 2020 task structure. National Lab reps work directly with the task teams to expedite application of lab technology to the priority problems identified by the forest products industry. A similar structure has been developed for the refining industry, targeting the primary areas of interest

Table 1-1. Laboratory Coordinating Council Executive Committee

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Helena Chum (Chairwoman)	303-275-2949	helena_chum@nrel.gov
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Figure 1-9. A Brief Excerpt from the Glass Industry National Lab Capability Matrix

Research Area	Los Alamos	Oak Ridge	Pacific Northwest	Sandia
Production Efficiency				
Glass Physical Property Sensors	●			
Controls to Optimize Processes				
Energy Efficiency				
Improved Furnace Energy Efficiency				

● = Strength ● = Significant Capability ● = Capability

Note: The full matrix addresses the capabilities of 16 DOE National Labs in 43 glass industry-related technology areas. Descriptions, point-of-contact, and funding data are provided for each project listed in the matrix.

as defined by the industry vision and working documents. Industry-specific contact points and structures are being developed for each of the seven industries that are the focus of the IOF process.

Through these efforts, the Labs have been able to identify a number of opportunities where research teams composed of reps from several Labs can more effectively address an industry research priority than any single Lab could alone. These collaborative programs help bring the "best of the laboratories" forward to assist industry in solving the technical problems facing the private sector.

Specifying Lab Technology Capabilities for Each Industry

The Lab Coordinating Council is developing a series of capability matrices that map specific lab capabilities with the technology needs of each of the seven energy intensive IOF industries (Figure 1-9). These documents will serve as valuable references for both individual company R&D programs and industry-wide technology roadmaps.

Because the Lab Coordinating Council has proved to be such a valuable resource for the IOF technology planning process, some industries have asked OIT to help orchestrate the creation of academic consortia-coordination councils and/or industry centers of excellence. These groups can perform roles similar to that of the LCC in expediting access to the specialized skills and expertise of the university community.

HOW OIT HELPS: IMPROVED ACCESS TO FEDERAL INDUSTRIAL R&D NETWORK

The Shortage of Information on Federal Industrial-related R&D

A key aspect of the Industry of the Future (IOF) process is to align Federal R&D resources with the needs of industry. To do this, a thorough inventory of Federal R&D efforts related to the seven industries involved in the IOF process is needed.

But anyone who has ever tried to find out what the Federal Government is doing in a specific technology area has discovered that this can be a very frustrating task. Government R&D activities are scattered throughout several agencies, and no central organization is charged with gathering, synthesizing, validating, and making available data describing all these efforts.

The absence of a single source of data on Federal Government activities in industrial-related R&D areas has several negative consequences, including

- Limiting the ability of private sector firms to capitalize on technological advances that could enhance their competitiveness, efficiency, or environmental performance
- Failing to optimize the national and public benefit of federally supported R&D
- Frustrating the creation of public-private R&D partnerships

Hence, to help overcome the barriers that the lack of consistent, reliable data create in trying to get the most out of publicly supported R&D activities, OIT is developing two inventories of industrial-related R&D programs and projects — one focused on R&D efforts outside of DOE and the other on DOE projects. These inventories will enable

- Companies to identify DOE and other Federal R&D programs and projects of interest
- OIT to identify gaps in R&D as industry technology roadmaps are developed
- Industry and OIT to discover opportunities for new collaborative efforts

Federal R&D Program Databooks and Project Database

Federal R&D Program Databooks have been developed that contain information on Federal R&D programs related to the seven basic energy intensive industries covered by the IOF

initiative. These include the aluminum, chemical, forest products, glass, metal casting, petroleum refining, and steel industries. The databooks provide descriptions of all Federal programs that may be performing R&D in technology areas related to these industries. Information included for each program includes title, agency and program address, description, point-of-contact, and estimated funding.

A separate project-level, Federal R&D database system is being developed in Microsoft Access software and will be available through OIT's homepage in mid-1997. The database will provide detailed information about current ongoing federally sponsored R&D projects. Each project record will contain information on project title and description, agency sponsor, program name, technology and industry area, participants, project status and plans, anticipated benefits, funding data, and point-of-contact. Keywords in the database will enable users to perform a variety of searches by industry, technology area, agency, participant, etc. A hard copy of the project database will also be developed for each industry to assist in the IOF roadmapping process.

DOE Industrial Projects Locator

OIT also produces and maintains the DOE Industrial Projects Locator (IPLocator) database. This is an electronic inventory of current DOE R&D projects relevant to several industries, including the seven basic industries that are the focus of the IOF initiative. The IPLocator provides a user-friendly mechanism to obtain information on current or recently completed DOE R&D projects through designated points-of-contact at DOE and its National Lab complex. The current version of the database, IPLocator Release 2.0, contains about 1000 R&D project records. The IPLocator is available in both a stand-alone and Internet version, which is accessible through the OIT website.

Each record in the IPLocator contains information on the R&D project title, description, funding history, and point(s)-of-contact for further information. The record is also classified to identify the major technologies and industries which best indicate where and how the project could be potentially applied when it is completed. The IPLocator projects can be searched for information by using freetext and keyword searches, as well as through industry and technology classifications to quickly create systematic lists of projects by industries and/or technologies.

Requests for more information on the IPLocator can be addressed to the Office of Industrial Technologies (EE-20), U.S. Department of Energy, Washington, DC 20585 or via e-mail to iplocator@pnl.gov.

HOW OIT HELPS: FINANCIAL ASSISTANCE AND R&D PARTNERSHIP MECHANISMS

The Financial Assistance Process

OIT carries out a significant part of its mission by offering financial assistance to qualified organizations in the public and private sectors in support of R&D that meets OIT's program objectives. Financial assistance agreements are legal instruments in the form of either a cooperative agreement or a grant.

A financial assistance instrument is primarily used to transfer money, property, services, or anything of value or use from the federal government to the recipient. Typically, financial assistance is used to fulfill a public intent of support or stimulation authorized by federal statute.

A grant would be awarded when no substantial involvement is expected between DOE and the recipient during performance of the activity; a cooperative agreement would be used when substantial involvement between DOE and the recipient is expected.

The process of administering financial assistance usually begins with a formal public announcement. Several types of solicitation and public notice instruments are used by OIT to communicate information regarding its objectives, statement of work, and the form of financial assistance award that it is offering.

Competitive Program Solicitations – Most of OIT's funding for R&D is awarded through competitive program solicitations. A solicitation for financial assistance is used to request applications for DOE financial assistance awards. The solicitation invites submission of applications or proposals within a prescribed period of time. Proposals submitted in response to a competitive solicitation are evaluated and awarded according to the selection criteria specified in the solicitation.

Solicitations are also issued by OIT through the **Small Business Innovation Research (SBIR)** program, which is managed by DOE's Office of Energy Research. The purposes of SBIR are (1) to stimulate technological innovation, (2) to use small business to meet Federal R&D needs, (3) to encourage participation by minority and disadvantaged persons in R&D, and (4) to increase private sector commercialization of innovative R&D. Applications are accepted for competitive evaluation in response to a program solicitation issued once a year for the first phase of the three-phase program. Awards are made for an estimated 6-month project period in an amount not to exceed \$75,000. Phase I awardees are eligible to compete for Phase II funding, not to exceed \$750,000, for a two-year project period to further develop their work. For the commercialization phase (Phase III), the small business must seek funding from outside the SBIR program.

Noncompetitive Financial Assistance – When providing financial assistance, noncompetitive awards by OIT can occur as a result of the following:

- Unsolicited proposals or responses to Notice of Program Interest (NOPI)
- The decision that only one recipient can be adequately responsive to the support and stimulation being provided by DOE
- Broad announcements for nonsimilar innovative responses

An unsolicited proposal is a proposal for DOE financial assistance that is not submitted in response to a solicitation or that is submitted in response to an NOPI. An unsolicited application must propose an innovative idea, method, or approach. An NOPI provides information about a particular DOE program interest in obtaining research applicable to general problem areas or program objectives. Applications submitted in response to an NOPI are evaluated as an unsolicited application.

An unsolicited proposal may be accepted by DOE if it

- Demonstrates a unique and innovative idea, method, or approach or demonstrates a unique capability of the submitter
- Is meritorious based on a general evaluation
- Would not be eligible for financial assistance under a recent, current, or planned solicitation

In the unsolicited proposal, the proposer must describe the objectives and pertinence of the proposed work to DOE; the rationale of the approach; the methods to be pursued; the qualifications of the investigators and the institution, if applicable; and the level of funding required to achieve the objectives. If accepted, an unsolicited proposal may result in an acquisition (contract) or a financial assistance (grant or cooperative agreement) award.

Partnership Mechanisms

Some of the mechanisms available for industrial participation in OIT programs include the following:

Cost-shared Financial Assistance Awards and Cooperative Agreements – A financial assistance award is a legal instrument reflecting a negotiated agreement between industry and

HOW OIT HELPS: FINANCIAL ASSISTANCE AND R&D PARTNERSHIP MECHANISMS

the government and is usually cost-shared. To protect proprietary interests of private parties, the government may agree not to disseminate commercially valuable data that is generated under a cost-shared financial assistance award for a specified period of time.

Cooperative agreements may also reflect a relationship between the federal government and state or local government or universities in order to support or stimulate research. In cooperative agreements, substantial involvement is anticipated between DOE and the recipient during the performance of the contemplated activity.

Cooperative Research and Development Agreements

(CRADAs) – CRADAs are agreements between government laboratories and nonfederal parties in which both participants provide personnel, services, facilities, or equipment to conduct specified R&D. The nonfederal parties may also provide funds, as no direct funding is provided by the laboratory. Rights to inventions and other intellectual property are negotiated between the laboratory and participant.

R&D Consortia – Consortia are arrangements involving multiple federal and nonfederal parties working together toward a common R&D objective. Funding for R&D consortia may be shared, but usually no funds are exchanged between participants.

Exchange Programs – These programs allow government or laboratory employees to work in industry facilities, and industry personnel to work in government labs and facilities. Exchange programs enhance technical capabilities and are used to support research in specific areas. Costs are borne by the organization sending the personnel. Intellectual property rights are set forth in the exchange agreement.

User Facility Agreements – These agreements permit private parties to conduct R&D at a DOE laboratory. For proprietary R&D, the laboratory is paid for the full cost of the activity. If the work will be published, the cost can be adjusted. Intellectual property rights generally belong to the private-party user of the facility.

Work-for-Others (WFO) Agreements – WFO agreements accommodate proprietary work for a nonfederal party done by technically qualified government laboratory staff using laboratory facilities with full costs charged to the party. Title to intellectual property generally belongs to the party sponsoring the work. The government retains a nonexclusive royalty-free license to such intellectual property.

Intellectual Property Rights

Rights to intellectual property developed as a result of DOE's financial assistance and R&D partnership mechanisms can be quite varied and depend on factors such as the nature of the technology, the contracting instrument, the recipient cost-share, the type of performing organization, and the source of funding. The financial assistance award is the principal mechanism used by OIT to support R&D, which almost always involves recipient cost sharing of 20% to 50%. Generally, DOE will honor requests for intellectual property rights to awardees who substantially cost-share the development of new concepts in non-nuclear or nondefense applications.

Financial assistance awards are based on the premise that it is in the public's interest for the work to be supported by DOE. Successful OIT-supported technologies help create jobs, stimulate economic growth, and improve the Nation's energy efficiency. Benefits are conferred to both the producer and consumer of these technologies, as well as the Government, through increased tax receipts and so on.

DOE financial assistance awards do not entitle Government to ownership of any pre-proposal know-how nor is the knowledge contained in proposals available to the public under the Freedom of Information Act. Financial assistance awards can protect proprietary information from public disclosure for up to five years. However, data on the performance characteristics of devices or systems under development must be provided to the Government. DOE has the right – indeed, the responsibility – to verify performance data of any technology supported through financial assistance awards. This is in order to affirm any efficiency, or environmental or other performance characteristic claimed for the technology.

HOW OIT HELPS: TECHNOLOGY ACCESS

Exercising OIT's Commitment to Technology Deployment

OIT supports an array of technology access programs, activities, and partnerships intended to help overcome barriers to market acceptance of new energy-efficient, environmentally friendly, competitiveness-enhancing technologies. OIT's portfolio of technology access mechanisms includes the following programs and activities:

- NICE³ grants
- Inventions and Innovation grants and assistance
- Motor Challenge
- Climate Wise
- Industrial Assessment Centers
- Technology transfer

These activities are described briefly below and in greater detail in Part 5 of this report.

NICE³

Participants in the National Industrial Competitiveness through Energy, Environment and Economics (NICE³) program receive one-time grants of up to \$425,000 to demonstrate industrial technologies showing promise for saving money while improving energy efficiency and reducing waste. Some of the goals of the program are to

- Increase cooperation between Federal, State, and local energy, environmental, and economic development organizations
- Catalyze cleaner manufacturing processes
- Conserve energy and energy intensive feedstocks
- Reduce industrial emissions and wastes
- Improve industrial cost-competitiveness

The program provides competitively selected grants to states in partnership with industry to foster wide application of demonstrations of innovative technologies that improve competitiveness through energy efficiency, pollution prevention, and waste reduction. NICE³ has sponsored 58 such projects since the program was initiated in 1991. Funding averages \$330,000 per project. OIT funding of individual demonstration projects cannot exceed 45% of the total cost of the effort. The balance must be provided by the state and private sector partners in the projects.

Inventions and Innovation Grants and Assistance

OIT's Inventions and Innovation program provides technical and financial assistance to independent inventors. It employs several activities that provide funding and commercialization training

OIT'S TECHNOLOGY ACCESS PROGRAMS PROMOTE NEW TECHNOLOGIES AND HELP THESE TECHNOLOGIES OVERCOME MARKET BARRIERS.

that support the development of energy-saving inventions for small business and independent innovators and inventors.

The Innovative Concepts program component assists inventors (with grants up to \$25,000) in the early stage of concept development. The Energy-related Inventions program component assists inventors (with grants up to \$100,000) during any stage of invention development.

The Inventions and Innovation program also sponsors Commercialization Planning and National Innovation Workshops to educate inventors about the process of technology commercialization. Participants in the program also receive no-cost market and technical evaluations of their inventions.

Motor Challenge

Motor Challenge is an industry-government partnership to promote a systems approach in selecting, operating, and managing efficient motor systems. Because 70% of industrial electricity is used to power motor-driven systems, there are large opportunities for energy savings. Over the past several years, Motor Challenge has helped companies realize savings of 20% to 50% by properly optimizing electric motor systems.

HOW OIT HELPS: TECHNOLOGY ACCESS

By participating in Motor Challenge, companies and organizations are able to access numerous products and services that help them optimize the design, operation, and efficiency of electric motor systems. Among the program activities that Motor Challenge partners may participate in include

- Showcase demonstrations
- Allied partnerships with suppliers, distributors, and other service-oriented organizations
- Excellence Partners recognition program
- Market assessment and program evaluation

Climate Wise

A jointly sponsored initiative of OIT and EPA, Climate Wise engages private sector industrial firms in partnerships to reduce their greenhouse-gas emissions by adopting energy efficiency and pollution prevention technologies and practices.

Climate Wise partners agree to develop an action plan to (1) initiate, (2) expand, or (3) accelerate a set of cost-effective measures to improve efficiency and protect the environment. To help them execute their plan, Climate Wise private sector partners receive access to a variety of technical and economic resources. These include

- Guidance in developing their action plan to reduce greenhouse-gas emissions
- Leads to financial and technical resources
- Connections to other Federal programs
- Information tools
- Workshops and seminars
- Opportunities for public recognition, and
- Regional collaboratives

Industrial Assessment Centers

Many small and medium-sized manufacturers simply lack or find it difficult to acquire reliable information about available and emerging technologies that could improve their energy efficiency, cost competitiveness, and environmental performance. OIT's Industrial Assessment Centers (IACs) provide no-cost energy and environmental audits for such companies.

Since 1978, IACs have performed over 6000 such assessments for small and medium-sized firms. The IAC teams — consisting of university engineering students led by experienced faculty members — look for opportunities to improve energy efficiency and reduce waste and pollution and improve productivity. On average 50% of IAC recommendations are implemented at an average savings amounting to \$55,000 for companies audited.

To receive an assessment, (1) firms' annual sales must not exceed \$75 million, (2) their employment must be less than 500, (3) they must lack in-house technical staff capable of performing energy audits, and (4) their annual energy cost must be between \$100,000 and \$1,750,000.

Technology Transfer

Even though the energy efficient and pollution preventing technologies supported by OIT have the potential to save time, money, and energy, there are still many barriers that must be overcome before they are adopted by manufacturers. OIT uses a wide variety of methods — including person-to-person contact, printed materials, and the media — to help overcome these barriers and get innovative industrial technologies into the marketplace and onto the shop floor.

Person-to-person Contact — One of the most effective forms of technology transfer is person-to-person contact, and OIT and its partners rely on conferences, expos, site visits, and meetings to reach many people. Field demonstrations are another useful person-to-person tool. Once a new technology is successfully operating, potential users are invited to the demonstration site to view it.

Printed Materials — OIT also produces a variety of printed materials describing the organization's work and successes. The office newsletter *Benefits and Breakthroughs* is distributed to over 5000 partners, companies, trade associations, and State agencies, which often further distribute it to their members or constituents. The OIT brochure, case studies, and other publications are distributed upon request at conferences and through the Energy Efficiency and Renewable Energy Clearinghouse. Technology fact sheets are distributed to industries and associations as appropriate.

Media — Another effective and economical method of reaching our target audience is through the media. Research has shown that members of the industrial community rely a great deal on trade press and journals to become aware of innovative technologies. Hence, OIT vigorously and continuously supplies information about major breakthroughs and improved processes to a lengthy list of trade journals; associations; and, when appropriate, popular media. This enables OIT to inform the broadest number of potential users about innovative technologies in our portfolio.

QUANTITATIVE BENEFITS OF OIT PROGRAMS

What's the Bottom Line?

OIT provides an assortment of services to its customers in U.S. industry. This includes R&D funding support, the facilitation of industry-wide technology planning and resource sharing, and the dissemination of knowledge and information about a wide range of innovative technologies, processes, and business practices. But what's the bottom line? What is the potential return on the public funding and other resources invested in OIT's program?

To help answer these critical questions, OIT has established a system for quantifying the potential benefits (Quality Metrics, or QM) of its portfolio of activities. Below is a tabulation summarizing the estimated benefits of OIT's programs for the year 2010. More detailed estimates of some of these metrics are provided later in this report, and the methodology used to develop the data is described in an appendix.

The QM data help show the huge potential for energy savings from the OIT program. The data also help quantify the affiliated greenhouse-gas and combustion-related emissions reductions that would accompany these energy savings.

Figure 1-10. Estimated Energy and Nonenergy Cost Savings of OIT Programs, 2010

Source: OIT Quality Metrics database

In addition, the QM data help show how OIT R&D programs offer the potential for many other important benefits to industry and the nation in addition to energy savings. OIT's QM data help demonstrate, for example, that the expected payoff in productivity, operating, materials, and other nonenergy costs exceeds that expected for energy alone (Figure 1-10).

Table 1-2. Estimated Benefits of OIT Programs, 2010

OIT Planning Unit	Total Primary Energy Displaced	Direct Oil Displaced	Energy Cost Savings	Nonenergy Cost Savings	Carbon Equivalent Emissions Reduction	NO _x Reduction	Particulates Displaced	VOCs Displaced	SO _x Reduction	Other Wastes Displaced
Units	Quads	Million Barrels	Billion \$ (1995 \$)	Billion \$ (1995 \$)	Million Metric Tons	Million Metric Tons	Million Metric Tons	Million Metric Tons	Million Metric Tons	100 Thousand Tons
Advanced Materials & CFCCs	0.76	1.13	2.91	3.32	13.25	0.113	0.063	0.0020	0.31	
Aluminum	0.47	0.61	2.23	0.52	8.38	0.073	0.034	0.0010	0.19	1.66
Chemical	1.37	130.27	7.87	7.48	24.03	0.162	0.012	0.0020	0.44	76.48
Climate Wise	0.09		0.5	1.0	1.4	0.000			0.00	
Advanced Turbine Systems & Cogeneration	0.31	4.30	1.27	0.93	5.14	0.040	0.028	0.0010	0.11	0.00
Forest Products	0.57	0.71	2.92	3.08	12.75	0.142	0.120	0.0000	0.37	1.9
Glass	0.12	1.26	0.55	0.05	2.01	0.017	0.006	0.0000	0.04	2.33
IACs	0.12	0.12	0.7	0.8	1.5	0.000			0.00	
Inventions & Innovations	0.09	2.20	0.22		2.29	0.027			0.08	
Metal Casting	0.02	0.00	0.10	0.22	0.42	0.004	0.002	0.0000	0.01	0.23
Motor Challenge	0.14		0.6	1.3	2.2	0.100			0.26	
NICE ¹	0.60	11.60	2.73	7.07	12.24	0.122	0.083	0.0030	0.33	58.4
Petroleum Refining	0.66	89.71	4.14	5.33	12.25	0.084	0.006	0.0010	0.22	73.40
Steel	0.08	0.16	0.24	1.67	1.77	0.020	0.018	0.0000	0.06	9.42

Source: OIT Quality Metrics database

UNDERSTANDING OUR CUSTOMERS' NEEDS: BASELINE TRENDS AND ANALYSIS

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TRENDS IN INDUSTRIAL SECTOR ENERGY USE

Lack of Improvement in Energy Efficiency Contributing to Record Usage

Primary energy use has been rising in industry almost steadily since 1983. Indeed, in 1994 industrial energy use in the United States reached its highest level ever — about 33.7 quadrillion Btu (quads). This was about 38% of all the energy used in the United States. Net energy use — the amount of energy actually consumed by industry, which excludes electric utility generating and transmission losses — was 26.6 quads.

While industrial energy use has been rising, industrial energy intensity has been holding fairly steady over much of the past decade. Often used to gauge trends in the efficiency of energy use, industrial energy intensity is the amount of energy used to produce a unit of output (typically, Btu of energy per dollar of output or gross domestic product (GDP)). The sector-wide lack of improvement in energy efficiency over the past decade

- Contrasts sharply with the significant improvements that were made during the previous decade
- Has contributed to the continuing growth in industry's energy use

Figure 2-1. Industrial Energy Intensity, Consumption, and GDP, 1974-1994

Note: Energy intensity = industrial energy use per dollar GDP

Sources: Annual Energy Review 1994 and Monthly Energy Review, May 1996, EIA

Figure 2-2. Industrial Energy Consumption by Fuel, 1974-1994

Source: Annual Energy Review 1994, EIA

Gas and Oil Predominate, Electric Power Use Increases

The energy mix used by industry has changed only modestly over the last two decades (Figure 2-2). Petroleum and natural gas have supplied between 30% and 40% of industry's energy demands for more than 30 years. About half the petroleum products and 10% of the natural gas consumed by industry is used as feedstock to produce plastics, fertilizers, asphalts, and similar materials rather than as heat and power.

Since 1960 the use of electricity in industry has doubled, from 7% to 14% of the energy mix. This is partially because of the growth in fabrication and assembly industries that are more reliant on electricity for their energy needs than are the basic materials and process industries (see following page for discussion).

THE MOST ENERGY INTENSIVE INDUSTRIES

Seven Industries Account for About 80% of All Manufacturing Energy Use

About 83% of industrial energy is used in the manufacturing sector. Nonmanufacturing industries — including mining, oil and gas extraction, construction, and agriculture — account for about 17%. Within manufacturing, industries primarily engaged in fabrication and assembly account for about 20% of energy use. The balance of manufacturing energy use, about 80%, is consumed by a total of just seven highly energy intensive industries. These industries include petroleum refining, chemical, forest products, steel, aluminum, metal casting, and glass.

These seven industries are the largest energy-using industries because they are each involved in chemically or physically transforming matter. These industries employ technologies that rely on the direct application of heat to break and rearrange molecular bonds through chemical reactions. Massive amounts of energy are required to do the work of breaking up and rearranging molecules, the essence of what these industries — sometimes called the materials and process industries — do.

What the Most Energy Intensive Industries Do with Fuel and Power

Figure 2-4 shows the principal functional uses of energy in the materials and process industries. Steam, produced in boilers and cogenerated, represents the largest functional use of energy in the materials and process industries. It is particularly important in industries such as paper, petroleum refining, and chemical — industries that deal largely with low-temperature organic materials. The heavy use of steam in these industries makes them particularly attractive for cogeneration systems.

Direct process heat — generated in furnaces, ovens, kilns, and similar vessels — represents the second largest use of energy in these industries. It is used for a diversity of processes that include fluid heating, metals treating, melting, smelting, forming, calcining, drying, and curing. Though widely used in all the materials and process industries, direct process heat is especially important in the metal, ceramics, and glass industries. These industries work predominantly with high-temperature inorganic materials.

Figure 2-3. Estimated Manufacturing Energy Use by Industry, 1994 (end-use basis)

Source: EIA

Electricity for machine drives represents the third largest use of energy, which includes power for motor drives in pumps, fans, compressors, and materials handling or processing equipment. Other uses for energy include electrolytic processes (especially important in the aluminum industry), space heating, and lighting.

Large quantities of energy are also used as feedstocks in the chemical industry (petroleum, natural gas, etc.) and the steel industry, where carburized coal (coke) is used as a reductant in iron blast furnaces. About half the petroleum products used in industry are consumed as feedstocks rather than fuels.

Figure 2-4. Energy Use by Function in the Materials and Process Industries

THE COST OF ENERGY TO INDUSTRY

Industry Spends Over \$100 Billion Annually on Energy

Industry spent nearly \$104 billion on energy in 1993, with the bulk of expenditures (about 96%) used to purchase electricity, petroleum products, and natural gas (Figure 2-5).

Although on an end-use Btu basis electric power accounts for only about 14% of industrial sector energy use, on a cost basis purchased electricity accounts for 44% of total energy costs in the industrial sector.

Although industry's total energy expenditure of nearly \$104 billion is a very large sum, it represents only about 3% of total costs. But, like energy usage, energy costs vary substantially throughout industry. Paralleling their role as the largest energy users in industry, OIT's principal customers in the materials and process industries also have the largest energy costs. In most instances their total energy costs substantially exceed the 3% average for all industry (Figure 2-6).

Figure 2-6. Energy Purchases and Their Share of Production Costs by Industry, 1994

Source: 1994 Annual Survey of Manufactures, Bureau of the Census, Department of Commerce

Energy Bills for OIT Customer Industries Exceed 10% of All Costs

As the figure reveals, in such industries as steel, paper, and glass, energy costs exceed 10% of total costs. Moreover, in those industries that produce nitrogen fertilizers, aluminum, cement and chloralkali, energy expenditures are greater than 20% of all costs.

Energy prices have a direct impact on overall industrial energy consumption as well as the choice of fuels used. When energy prices are high, firms in energy intensive industries aggressively seek energy conservation measures and switch fuels to lower their energy costs. When energy prices are low, as they have been for some time, the economic attractiveness of energy efficiency investments decreases relative to other corporate investments. Hence, in the current climate investments in industrial energy efficiency technologies typically possess substantial productivity or environmental benefits as well.

Figure 2-5. Industrial Energy Costs

1993 Energy Expenditures: \$103.9 Billion

Source: EIA, State Energy Price and Expenditure Report 1993.

PROJECTIONS OF FUTURE INDUSTRIAL ENERGY USAGE

DOE's Energy Information Administration (EIA) projects that industrial sector end-use energy consumption will be between 29.1 quads and 34.4 quads in the year 2015. The corresponding average annual rates of growth in industrial energy use are expected to range between 0.5% and 1.3%.

EIA forecasts that the decade-long stagnation in industrial energy intensity will cease and that industrial energy efficiency will improve over the next 15 years. Among the factors contributing to the expected decline in industrial energy intensity are

- The gradual restructuring of industry toward knowledge intensive rather than materials intensive products
- Higher capacity use because of improved computer controls and just-in-time manufacturing methods
- Process efficiency gains due to higher energy prices and efficiency standards

Figure 2-7. Trends in and EIA Projections of Industrial Sector Energy Use

Note: End-use energy basis

Figure 2-8. Trends in and Projections of Energy Consumption in Selected Materials and Process Industries

Source: EIA

Figure 2-9. Projected Energy Intensity of Selected Materials and Process Industries, 1997-2015 (1997 = 100)

Source: EIA

ROLE OF THE MATERIALS AND PROCESS INDUSTRIES IN THE ECONOMY

Critical Links in the Manufacturing Food Chain

The finished materials and other inputs supplied by the most energy intensive industries constitute the beginning of the long and intricate “food chain” of the manufacturing sector of the economy.

While some of the products of the materials and process industries — gasoline and some paper products, for example — are sold more or less directly to consumers, the overwhelming preponderance of their products are inputs to other manufacturing industries. Indeed, many such industrial products — chemical feedstocks, fibers, cardboard, plastics, metal sheet and other forms, castings, lumber, and glass — typically require further manufacturing operations before they are transformed into consumable goods.

As shown in Figure 2-10, the products of the energy intensive materials and process industries are converted by other value-adding fabrication and assembly industries into a complex array of consumer, industrial, and national defense-related goods ranging from textiles and clothing, books and newspapers, furniture and household appliances, and computers and telephones to beverage cans and grocery bags, automobiles and aircraft, tractors and machine tools, tanks and submarines, and drugs and medical equipment.

Figure 2-11 is adapted from an article by Robert Ayres entitled “Industrial Metabolism.” It identifies the principal stages of transforming raw materials into manufactured goods. The goods-producing process typically begins with the extraction of raw materials that are subsequently refined by energy intensive processes designed to separate out impurities. These intermediate pure materials are then recombined (or synthesized) into finished materials. Typically this process entails the chemical or physical blending of multiple pure materials (or ingredients) to yield the specific properties desired by the industrial customer. Finished materials are then cast, machined, or otherwise fabricated into parts or components that can be assembled into manufactured goods. Ultimately, manufactured goods are either recycled or disposed of as waste.

Why These Are Often Called Basic Industries

Unfortunately, the critical role of these industries in the economy is often overlooked by the national media and misunderstood by the broader society. Because their products largely lose their identity in the process of being converted into usable consumer goods, mass media advertising is not widely practiced by many firms in these industries (the oil and some paper and chemical companies that occasionally retail directly to consumers are important exceptions).

Figure 2-10. Role of Materials and Process Industries in the Economy

ROLE OF THE MATERIALS AND PROCESS INDUSTRIES IN THE ECONOMY

Thus, firms in these industries often are not widely recognizable household names, which in turn contributes to lack of public appreciation of their roles in the economy. But from an economic and physical standpoint these essential industries quite literally underpin the entire industrial infrastructure. This is why these industries are often referred to as basic industries.

The energy intensive materials and process industries are a huge and critical component of the economy. In 1994, they shipped a total of \$896 billion worth of products. This included about \$333 billion in shipments by the chemical industry, \$297 billion by the forest products industry, and \$128 billion by the petroleum refining industry. In 1994 the total value added by these industries amounted to \$395 billion, meaning they directly accounted for about 25% of all value added by manufacturing and almost 5% of all of U.S. economic output.

Figure 2-11. Principal Stages in the Processing of Raw Materials into Manufactured Goods

Competitiveness Influences, Linked with That of the Rest of Manufacturing

On the whole, however, the U.S. materials and process industries are cyclical industries whose long-term growth at best equals or more commonly is slightly less than that of the overall economy. The slow growth trajectories often translate into low price/earnings (P/E) ratios for the stocks of companies in these industries. Despite the lack of the glamour that often accompanies high growth, high P/E industries, the materials and process industries underlie and support the entire manufacturing economy. The health, performance, and competitiveness of these industries are tightly intertwined with those of the rest of U.S. manufacturing.

Figure 2-12. Growth Trends in the Materials and Process Industries

Source: EIA

Figure 2-13. Materials and Process Industries Share of GDP

Sources: Department of Commerce; OIT estimates from Department of Commerce data

EMPLOYMENT, WAGES, AND CAPITAL INTENSITY

Huge and Well-paying Employer...

Commensurate with their large physical size, the materials and process industries are a major source of jobs in the American economy. In 1994, total employment in the materials and process industries was about 2.9 million workers. This was about 16% of U.S. manufacturing employment and about 3% of the nation's total nonfarm, private sector employment.

In addition to their direct employment, it is important to recognize the multiplier effect of these jobs. The Economic Policy Institute estimates that each job in the materials and process industries supports four workers employed in supplier, equipment, repair, finance, engineering, sales, and even government occupations.

Hourly wage rates in the materials and process industries typically exceed the average rates in all manufacturing by 12% and the average service sector job wage by 26% (Figure 2-15). In addition, during periods of strong economic growth, workers in these industries can often considerably boost their overall earnings with overtime pay. Moreover, health benefits are usually provided by the large corporations that account for many of the jobs in these industries.

...Especially Outside Major Metro Areas

Another important attribute of the employment profile of the materials and process industries relates to the fact that they often locate relatively close to the natural resource industries whose raw materials they process. For example, petroleum refineries are often located on shipping and storage routes used by oil producers. Pulp and paper mills are typically sited near large timber resources in the Northwest and Southeast. Several base metal smelters are situated in the Rocky Mountain and other mineral-rich districts.

The locational tendencies of many firms in the materials and process industries mean that they are often especially important sources of earnings and employment outside large metropolitan areas in rural and low-density population areas.

Table 2-1. Employment in Seven Energy Intensive Industries: Department of Commerce vs. Industry Trade Association Data

Industry	Dept. of Commerce	Industry Association
Aluminum	71,800	130,000+
Chemical	824,000	1,061,000
Forest Products	1,339,900	1,443,000
Glass	152,300	150,000+
Metal Casting	204,500	210,000
Petroleum Refining	71,700	Not available
Steel	221,100	170,000
Total	2,885,300	3,164,000+

Figure 2-14. Employment Trends in the Materials and Process Industries

Sources: Annual Survey of Manufactures and Census of Manufactures (various years), Bureau of the Census

Figure 2-15. Wages in the Materials and Process Industries Compared to Those in Other Industries

Sources: 1994 Annual Survey of Manufactures, Bureau of the Census; Statistical Abstract of the United States 1995 (Table #668), Department of Commerce

EMPLOYMENT, WAGES, AND CAPITAL INTENSITY

Large Capital Intensity Means Big Multiplier Effect

Another compelling indicator of their role in the economy is the quantity of capital invested in the materials and process industries. Because of the huge size, throughput, and scale economies of these industries, they are among the most capital intensive of all manufacturing industries. Collectively, these industries accounted for over a third of all new capital expenditures in manufacturing in 1994. Furthermore, with the exception of the aluminum industry, all the materials and process industries exceeded the manufacturing average for capital expenditures as a percentage of sales, as shown in Figure 2-16. These industries are also among the largest in terms of overall capital investment as measured by the value of gross stocks of fixed private capital (Figure 2-17).

Figure 2-16. Capital Expenditures in the Materials and Process Industries

Source: 1994 Annual Survey of Manufactures, Bureau of the Census

Figure 2-17. Manufacturing Net Stock of Fixed Capital (end of year, 1993)

Source: Survey of Current Business, August 1994

Economic Data in This Report Are from Official Government Sources

Unless otherwise indicated, in this report economic statistics pertaining to value of industry shipments, percentage of GDP, employment, wages, foreign trade, capital investment, and so on are from official government sources.

In some instances, OIT customer industries collect their own industry statistics through trade associations, trade journals, or other means. For a number of reasons, frequently this data will differ from official government statistics as shown by Table 2-1. Industry sources often consider data gathered by their own associations more complete, accurate, or current than government-collected data for the same categories.

However, in this report, use of government statistics helps ensure consistent industry definitions and uniform time intervals, which in turn enable more reliable aggregation across industries and more dependable interindustry comparisons.

TRADE

Around a Seventh of U.S. Merchandise Trade

The materials and process industries also play a huge role in our Nation's trade picture. In 1994, when they employed nearly 3% of U.S. workers and produced nearly 5% of U.S. GDP, they also accounted for over 14% of our total merchandise trade, as shown in Figure 2-18. The huge role that trade in commodities and products manufactured by the materials and process industries plays in our Nation's total trade picture underscores the necessity that these industries maintain a high degree of competitiveness.

Some U.S. materials and process industries — such as organic chemicals, pharmaceuticals, and pulp mills — are considered among the most technologically advanced and competitive in the world. The large trade surplus in chemicals contributed to total exports of about \$79 billion by the materials and process industries in 1994.

On the other hand, other industries — such as steel and petroleum refining — struggle intensely with foreign competition despite extensive modernization and restructuring over the past decade. These industries are important contributors to our nation's overall trade deficit. Heavy reliance on foreign suppliers of refined oil products and steel, among many other items, helped boost total imports of commodities produced by the materials and process industries to \$89 billion in 1994 (Figure 2-19).

Figure 2-18. U.S. Merchandise Trade in 1994:
Role of the Materials and Process Industries

Source: Trade & Employment, 4th Quarter 1995 & 1994 (TM/95-04); Departments of Commerce and Labor

Figure 2-19. Trade Balances for Materials and Process Industries, 1994

Source: Trade & Employment, 4th Quarter 1995 & 1994, Departments of Commerce and Labor

Commodity Products Mean Intense Foreign Competition

Regardless of their current trade balance, however, the bottom line is that virtually all the materials and process industries face strong international competition. In some foreign countries, the large number of workers in these industries translates into strong political support and subsidies. In addition, the relative maturity of these industries and their often highly cyclical nature sometimes lead to worldwide overcapacity and depressed prices, as has been the recent case in the steel and petrochemical industries. The U.S. materials and process industries are also facing increasingly intense competition from resource-rich developing countries that want to add greater value to raw commodities such as oil, minerals, and lumber.

RESEARCH AND DEVELOPMENT

Research and Development Levels Below Average

Because of the large employment by the materials and process industries, the magnitude of international trade in their products, their contribution to GDP, and their critical linking role between the extractive and fabrication and assembly industries, it is essential that this sector of the economy remain highly competitive. Innovative technology to improve the energy efficiency, productivity, product quality, and environmental performance of the materials and process industries is critical to maintaining their international competitiveness.

Unfortunately, R&D spending in these high-wage, high-employment, high-multiplier industries — with the lone exception of the chemical industry — averages to only about 1% of sales. This is fully two-thirds below the average of all manufacturing, as indicated in Figure 2-20.

Consistent with its innovation-and-growth culture, the chemical industry by contrast spends nearly twice as much on R&D as the average of all U.S. manufacturers.

In general, however, the below-average R&D spending by the materials and process industries is indicative of mature markets and mature technologies. In addition, the scale-economy nature of these industries translates into large capital requirements, long payback periods, high risk, and conservative innovation strategies.

Figure 2-20. R&D Expenditures in the Materials and Process Industries

* Estimated

Sources: *Research and Development in Industry: 1994*, National Science Foundation; *1994 Annual Survey of Manufactures*, Bureau of the Census

Yet continuous innovation and improvement are increasingly necessary for success in the competitive global economy. The characteristic tendencies of many firms involved in making and processing materials and fuels suggest a strong need for joint participation by multiple companies and federal agencies in collaborative research and technology development partnerships.

Table 2-2. R & D Funding by Industry, 1988-1994 (millions of constant 1992 \$)

Area	Basic			Applied			Development		
	1988	1994	Change	1988	1994	Change	1988	1994	Change
Forest Products	\$98	\$227	132%	\$374	\$630	68%	\$593	\$537	-9%
Chemical	\$961	\$2475	158%	\$4921	\$5130	4%	\$6695	\$8167	22%
Petroleum	\$91	n/a	n/a	\$1177	\$655	-44%	\$1027	\$1046*	2%
Stone, Clay, Glass	\$160	\$48	-70%	\$425	\$167	-61%	\$224	\$312	39%
Ferrous Metals	\$3.5	\$18	414%	\$144	\$80	-44%	\$145	\$131	-10%
Nonferrous Metals	\$84	\$79	-6%	\$113	\$116	3%	\$231	\$215	7%
Manufacturing	\$3433	\$4507	31%	\$16988	\$14512	-15%	\$48585	\$50865	5%
Industry	\$4073	\$5789	42%	\$19200	\$18450	-4%	\$54163	\$68270	26%

* 1993 data

Source: *Research & Development in Industry, 1992 and 1994*; National Science Foundation

NATIONAL DEFENSE SIGNIFICANCE

The Critical Role of These Industries in Supporting National Defense

The materials and process industries not only provide the foundation of our nation's industrial base, they are also essential in supporting a secure national defense. If high-tech industries such as aerospace, transportation equipment, and microelectronics supply the muscle and central nervous system of our national defense, then the materials and process industries provide the backbone and lifeblood to support our Nation's military needs.

Tanks and all-terrain vehicles, missiles and bombs, small arms and ammunition, fighter aircraft and helicopters, nuclear submarines and aircraft carriers, radios, computers and communications systems, and intelligence and logistical systems are all fashioned from materials and propelled by fuels manufactured by the materials and process industries.

Indeed, the materials and process industries are essential to national defense in two fundamental ways:

- On one hand, they convert raw materials into durable items like metal alloys and polymer composites that are used to make the weapons and supporting systems necessary to conduct successful combat operations.
- On the other hand, their products help sustain military operations anywhere in the world, with such essential nondurable supplies as fuel and clothing.

A lengthy list of expert panels and reports have testified to the critical roles of the materials and process industries as suppliers to both the military directly and the industries that manufacture weapons and other military hardware. For example, the General Accounting Office (GAO) has identified more than 200 four-digit SIC code industries as being defense-critical. These industries provide supplies and weapon systems to meet threats to the Nation, ranging from incidents of terrorism to full-scale global conflicts. According to GAO, in efforts to assess the viability of defense-critical industries, the Department of Defense (DOD) has repeatedly identified the major materials and process industries, including paper mills, various chemical products, petroleum refining, and primary and fabricated metals and machinery.

As recent efforts to define defense-critical technologies have become more refined — and focused on computers, microelectronics, advanced propulsion systems, and sensors — DOD has continued to emphasize materials and manufacturing as critical areas. For example, in DOD's influential Defense Critical Technologies Plan, 21 critical technologies were identified and classified into five clusters, including materials and manufacturing. The materials and manufacturing cluster includes composite materials, high-energy density materials, and flexible manufacturing.

THE MATERIALS AND PROCESS INDUSTRIES ARE ESSENTIAL TO NATIONAL DEFENSE.

INDUSTRIAL WASTE AND POLLUTION

The Genesis of Industrial Waste and Pollution

As industry transforms materials into useful products, numerous by-products are created. When these by-products have economic value, they are sold as secondary products or further transformed to create other useful materials. Unfortunately, an enormous amount of industrial by-products has little or no economic value and is discarded as waste. When this waste is controlled through regulation, it is often considered pollution.

When industry generates material waste, valuable energy is often wasted as well. This wasted energy is accounted for in the embodied energy of unused or poorly used raw materials, in the energy content of waste streams, and in the energy required to manage and dispose of wastes. This is especially true for the energy intensive materials and process industries where waste generation and excessive energy consumption present opportunities for more efficient processes.

Because they are so closely linked, decreased energy use and waste and pollution reduction can be complementary goals. By preventing pollution, industry can reduce fuel consumption as well as the energy used to treat and dispose of wastes.

Industrial Waste and Pollution: How Much and What Type?

Information on which to base estimates of the quantity of waste and pollution generated by industry is generally poor and must be pieced together from a variety of sources that use widely differing definitions.

However, the best available estimates suggest that U.S. industry generates more than 14 billion tons of waste each year (Figure 2-21). These wastes include gaseous emissions, solid wastes, sludges, and huge amounts of wastewater. Most of the wastes originate in the manufacturing sector, which generates roughly 9 billion tons per year. Of the remaining industrial wastes, about 5 billion tons per year come from coal and nonfuel mining, oil and gas extraction, and agriculture. This estimate is at best a rough approximation of the true extent of waste generation.

The remainder of Part 2 describes the principal types of industrial waste and pollution based on data synthesized from a variety of data sources. The discussion is focused primarily on the principal categories of waste and pollution as defined by various environmental statutes.

It is important to bear in mind that this discussion is focused on the quantitative dimensions of industrial waste. But from a legal, human health, or cost perspective, the qualitative dimensions of a million tons of highly toxic waste (for example) in many respects far outweigh the quantitative significance of a billion tons of essentially inert nonhazardous waste.

Figure 2-21. Industrial Waste Categories

Source: Manufacturing Consumption of Energy 1991; EIA. National Biennial RCRA Hazardous Waste Report 1989; EPA Report to Congress: Solid Waste Disposal in the United States; EPA 1988.

HAZARDOUS AND TOXIC WASTES

Hazardous Wastes

Hazardous wastes present risk to the environment and human health and are therefore closely regulated. Hazardous waste is characterized as having toxic, corrosive, reactive, or ignitable properties. In addition, mixtures containing specific (listed) substances are considered hazardous. According to EPA, in 1989 about 193 million tons of hazardous solid waste were managed in treatment, storage, and disposal facilities regulated under the Resource Conservation and Recovery Act (RCRA). Although data collection covered 20,732 sites throughout the United States, many hazardous wastes are managed outside the scope of the RCRA permitting system. Analysis of the hazardous waste data for 1987 indicates that the reported wastes represent only about 40% of the total estimated hazardous waste stream in industry. This suggests that all of industry generated close to 500 million tons of hazardous waste in 1989.

Much of the hazardous waste generated in the United States is concentrated in a small number of large manufacturing complexes. Of the 20,732 sites covered in the 1989 RCRA report, 60 sites (less than 0.5%) accounted for 93% of all wastes. Of these sites, 40 are in the chemical industry, which accounts for 91% of hazardous waste generation in manufacturing. Other industries that generate large quantities of hazardous waste are petroleum refining, electronics and electric equipment, fabricated metal products, and primary metals. More than 90% of the weight of hazardous wastes is wastewater.

Toxic Wastes

Toxic waste emissions from manufacturing are of special interest because of their potentially severe impact on the health of workers, local communities, and the environment. In 1994, U.S. companies released and transferred 3.03 million tons of toxic wastes (Figure 2-23). The chemical industry was responsible for the largest portion of these wastes, followed by the primary metals and petroleum refining industries. Together these three industries account for nearly two-thirds of the total toxic waste stream.

Topping the list of toxics was ammonium sulfate, which is often used as an agricultural fertilizer and is also a co-product of some chemical processes and a by-product of coke ovens. Other major toxics included widely used commodity acids (e.g., sulfuric, hydrochloric) and commonly used solvents and chemical building blocks (e.g., methanol, toluene, acetone, xylene, trichloroethane).

Figure 2-22. Industrial Hazardous Wastes by Industry

Source: National Biennial RCRA Hazardous Waste Report 1989, EPA

Figure 2-23. Industrial Toxic Wastes by Industry

Source: 1994 Toxic Release Inventory, EPA 1996

GREENHOUSE GASES AND AIRBORNE POLLUTANTS

Greenhouse-Gas Emissions

Greenhouse gases comprise a group of gaseous wastes that are associated with global climate change. Major contributors include carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons (CFCs). Carbon dioxide, the largest source of greenhouse gas, is produced by fossil fuel combustion and certain industrial processes (including cement manufacture, lime manufacture, limestone in steelmaking, carbon dioxide manufacture, soda ash manufacture and use, and aluminum production). In 1991, an estimated 2.3 billion tons of CO₂ was emitted by industry. Industrial methane emissions, which result from agricultural activities and energy production and use, were estimated at 18 million tons in 1991. Although significant uncertainty still remains about the magnitude of future climate change from greenhouse gases, the potential effects of sustained temperature rises (e.g., rising sea levels, availability of water, etc.) continue to be a cause for concern and study.

Airborne Pollutants

Airborne pollutants are gaseous by-products of fossil fuel combustion and other industrial activities. Several of these pollutants such as particulates, SO_x, NO_x, volatile organic compounds (VOCs), and CO contribute to poor urban air quality and regional air problems like acid rain. EPA has estimated that industrial sources account for more than 40% of all reactive VOC emissions, about 25% of SO_x emissions, and about 15% of NO_x emissions in the United States.

Elevated levels of these pollutants can lead to a variety of adverse health effects and have also been blamed for reduced crop yields and stunted forest growth. Ozone, for example, produced through chemical reactions that involve both NO_x and VOCs, is a major component of smog. Acidic deposition, or acid rain, occurs when pollutants (primarily SO_x, NO_x, and VOCs) form acidic compounds in the atmosphere and are later deposited on the earth by rain, snow, or fog. The detrimental effects of these acidic compounds on aquatic systems, forests, and human health are of major concern to the public.

In 1990, air emissions from the manufacturing industries reached more than 10 million tons (Figure 2-24). The highest producers of airborne pollutants are the chemical; petroleum refining; primary metals; pulp and paper; and stone, clay, and glass industries.

Figure 2-24. Air Emissions from the Materials and Process Industries

Source: National Air Pollution Estimates 1990-1991; EPA, October 1992

POLLUTION ABATEMENT COSTS

Costs of Waste Management and Pollution Control

The Department of Commerce (DOC) estimates that all of American business — including manufacturing, electric utilities, mining, and a variety of service and nonmanufacturing industries — spent \$77 billion for waste management and pollution control in 1994. These costs represent direct outlays for equipment purchases, operations, and maintenance but do not include a wide variety of indirect costs such as legal expenditures associated with waste management.

Manufacturing sector pollution abatement operating cost/capital expenditure data are collected by the Census Bureau in a survey of companies. DOC estimates that manufacturers spent roughly \$28.5 billion on pollution control equipment and operations in 1994 — nearly 1% of the total value of all manufacturing shipments (Figure 2-25). However, pollution control costs do not fall evenly among industries. The seven materials and process industries that are OIT's principal customers account for about 63% of all industrial pollution control costs.

Materials and Process Industries Have Highest Pollution Control Costs

Several measures can be used to assess effects that pollution control costs have on U.S. competitiveness. One approach is to consider pollution control costs as a portion of sales and value added. On average, manufacturers spend 0.8% of sales and 1.65% of value added on pollution control expenditures. However, once again, the average is misleading because of the great variance of these expenditures among industries. For example, the petroleum refining industry spends much more than this average — 4.2% of sales and 23.2% of value added — on pollution control. Other materials and process industries that spend more than the average include pulp and paper, steel, chemical, and aluminum.

Another, even more compelling indication of the impact of pollution control costs on U.S. competitiveness is the portion of capital expenditures that is allocated to this activity. In 1994, 7% of all capital expenditures by manufacturers were for pollution control equipment. However, once more the average is misleading. Four materials and process industries — petroleum refining, chemical, steel, and forest products — allocated on the average about 15% of their total capital expenditures to pollution control. U.S. petroleum refiners spent nearly 50% of their capital on pollution control. In contrast, most fabrication and assembly industries — including those such as textiles, automobiles, and machinery — devoted only about 2% or 3% of their capital expenditures to pollution control.

Figure 2-25. Manufacturing Pollution Abatement Costs by Industry

Note: Bureau of the Census

INDUSTRIES OF THE FUTURE INITIATIVE

The Steel Industry	38
The Aluminum Industry	45
The Metal Casting Industry	51
The Glass Industry	57
The Chemical Industry	64
The Petroleum Refining Industry	73
The Forest Products Industry	80

THE STEEL INDUSTRY

Economics and Competitiveness

Steel is vital to the United States for both national security and economic well-being and is the most basic and widely used metal in an industrial society. The industry that makes, shapes, and ships steel is a \$68-billion-a-year business that employs about 220,000 workers.

Historically, the steel industry has been largely divided into two principal segments: the predominantly ore-based integrated producers and the scrap-based nonintegrated producers. Integrated steel producers smelt iron ores to liquid pig iron in blast furnaces and refine the iron with added scrap in basic oxygen furnaces. Nonintegrated steel producers, on the other hand, rely primarily on scrap for their raw materials. Broadly speaking there are two types of nonintegrated mills: electric arc furnace (EAF) mills and specialty mills. EAF mills melt scrap in electric furnaces and utilize continuous casting and hot rolling mills to produce tonnage carbon steel products. Specialty mills, on the other hand, produce stainless, high-temperature, and other alloy steels for a variety of mostly niche markets.

In response to the numerous and severe competitive pressures confronting it in the 1980s, the U.S. steel industry has undergone profound restructuring. Over the past decade, U.S. steel companies have invested nearly \$30 billion in new process and product technologies. The industry has invested especially heavily in continuous casting, and this has helped improve industry-wide yield from around 70% (i.e., 30% in-process waste and scrap) 20 years ago to about 85% today. Such investments, together with new management styles and the closure of several outmoded plants, have contributed to the U.S. industry's remarkable turnaround. The industry has nearly doubled its productivity over the past 10 years, and it now takes, on average, just a little over 3 man-hours to manufacture a ton of steel — one of the best productivity rates among all steel-producing countries.

Still, many stresses continue to challenge the steel industry. Foreign and intermaterial competition as well as competition between the integrated producers and scrap-based EAF mills

Table 3-1. Steel Industry Profile

Value of Shipments	\$68.5 billion
Total Employment	221,000 jobs
Capital Expenditures	\$3.1 billion
Net Trade Balance	(\$11.4 billion)
Energy Consumption	1.8 quadrillion Btu
Pollution Control Costs	\$1.4 billion
Average Hourly Earnings	\$18.83

are forcing steelmakers to develop and invest in ever more efficient and quality-enhancing technologies. The growth of export-oriented steel production in developing countries will also continue to confront the industry and contribute to worldwide overcapacity and generally low prices until worldwide restructuring is complete. Customer demands for ever higher product quality and the cost of capital are among other major challenges facing the industry.

In addition, the threat of increased environmental legislation is a constant source of concern to the industry, and a number of pollution problems remain to be solved, such as:

- Particulate, NO_x, and SO_x emissions by sinter plants
- VOC emissions by coke ovens
- Treatment of blast furnace and basic oxygen furnace (BOF) sludges
- Iron- and steelmaking slags
- Treatment of EAF dust
- Treatment of rolling mill waste

In the long term, such factors will likely push the steel industry toward more simplified and continuous technologies that reduce both capital costs and environmental pollution and waste. Some EAF mills are planning to backward-integrate into the manufacture of iron while integrated mills are looking into thin-slab casting and other technologies introduced by the EAF mills. Hence, the industry may begin to evolve to a point where the formerly clear distinction between integrated and EAF mills starts to fade.

Figure 3-1. Index of Output per Employee-hour in the Steel Industry (1987 = 100)

Source: Bureau of Labor Statistics

Figure 3-2. Steel Industry Share of GDP

Source: DIT estimates from Department of Commerce data

THE STEEL INDUSTRY

Energy

In 1994 the U.S. steel industry consumed a gross total of 2.3 quads of energy, including electricity generation and transmission losses. This was about 2.6% of all energy used in the United States that year. Energy costs amount to about 20% of the total cost to manufacture steel, about \$50/ton. Nearly half of the industry's energy is derived from coal, most of which is used to produce coke for use in the blast furnace. Electricity and natural gas are other major energy sources.

Average energy use per ton of steel shipped varies from about 20.7 million Btu for integrated steelmakers to 8.1 million Btu for scrap-based EAF steel producers. EAF steelmaking is less energy intensive than basic oxygen furnace steelmaking because EAFs use 100% scrap as the charge versus about 25% by BOFs. Using scrap eliminates the most energy intensive step of the steelmaking process — the conversion of iron ore to iron in the blast furnace.

In 1994, the average energy intensity for the industry as a whole was 18.9 million Btu/ton of shipped steel. This was an improvement of about 40% from 20 years earlier, when 31.7 million Btu/ton of steel shipped was the industry average. Since about 1988, however, decreases in steel industry energy intensity have slowed. Increased energy requirements associated with environmental controls were a major factor contributing to this trend. While additional improvements in steel industry energy efficiency are anticipated, the pace and extent of these improvements will be strongly influenced by (1) the availability of capital to make the needed investments, and (2) environmental regulation.

Figure 3-3. Energy Use in Steelmaking, by Process Step, 1994 (end-use basis)

Source: American Iron and Steel Institute

Environment

In a typical year, 15% of the industry's capital investments go toward environmental projects. Indeed, the steel industry has invested more than \$6 billion on environmental control equipment in the last 20 years. This has enabled the industry to remove more than 95% of its air and water pollutants. In addition, solid waste production at a typical mill has been reduced by more than 80%. Furthermore, most hazardous wastes once generated by the industry are now being recycled or recovered for use.

The U.S. steel industry also recycles nearly 55 million tons of scrap metal a year — an amount greater than all other metals, paper, plastic, and glass combined. Over half of all steel produced in the U.S. is from recycled materials. The national recycling rate of appliances has grown from 4% to 62% in just 10 years; over 90% of all scrapped autos are recycled.

Despite its record of environmental achievements, steelmaking continues to generate many air pollutants, including carbon monoxide, nitrogen oxides, sulfur dioxide, and particulates. In 1993, the steel industry generated just over 30 million tons of solid wastes and residues such as slags, sludges, and dusts. That same year, the industry generated about 1.34 billion pounds of production-related Toxic Release Inventory chemical waste.

Clean Air Act provisions covering air toxics, permits, and enforcement will also significantly affect the industry, especially coke ovens. Even though coke oven emissions have fallen an average of 90% since 1970, increasingly stringent environmental regulations make operations at existing coke plants more costly and are speeding up the closure of several coke ovens. Cokemaking capacity decreased from approximately 42 million tons in 1980 to 24 million tons in 1992.

Figure 3-4. Steel Industry Pollution Control Cost Trends

Source: Bureau of the Census

STEEL INDUSTRY VISION OF THE FUTURE

Industry Vision

"Steel — A National Resource for the Future" is an industry-defined vision of what the steel industry is expected to look like in the years 2010-2020. The steel industry vision helps to define its R&D needs and provides a foundation for the industry and DOE to work together in developing a technology roadmap to help implement the vision. This, in turn, will enable the steel industry and DOE to collaborate in cost-shared R&D activities that are crucial to the industry's needs.

The steel industry vision document and its companion technology roadmaps will have a wide audience and help focus the agendas of a broad range of steel industry R&D providers, including universities, National Labs, R&D firms, equipment vendors, and private and Federal funding agencies. They will also help ensure that R&D activities address the highest priority needs of the industry. Partnerships will be formed with groups of steel companies, DOE and other government agencies, the National Labs, and States.

The steel industry's vision document broadly defines four critical areas where continuous improvement will be needed if steel is to retain its position as the material of choice for the 21st century:

- Production efficiency
- Recycling
- Environmental engineering
- Product development

Production Efficiency — The steel industry's technology needs are energy-efficient, environmentally friendly, and cost-effective production processes. Avoidance of the conventional coking process and utilization of waste iron-bearing dusts and sludges to produce virgin iron metal is of prime importance today. Improvements in productivity, cost reduction, and processes to produce near-net-shape products will greatly enhance the industry's competitiveness. Technologies should utilize in-plant energy sources to the maximum extent. The successful processes will have to be more closed and continuous; utilize a variety of energy sources; and limit, capture, and utilize waste. The concept of flexible manufacturing, which is receiving widespread acceptance, will require integration of technologies and information systems. Improvements in production efficiency will be reflected in higher quality products at lower costs. In addition to technological excellence, the availability of a highly skilled workforce will be critical for improved production efficiency. Hence, continuous training and education of employees will be needed.

Recycling — Pressures to reduce wastes, maximize the utilization of resources, and increase recycling will be major factors influencing the steel industry of the future. New processes are needed to raise the quality and availability of steel scrap while maintaining low cost. Recycling of waste products to recover virgin iron units and the technologies to achieve this would be another area of importance.

This will become more important if smaller iron-producing units can be established. The increasing number of EAFs will need such technology in the light of improving quality.

Continuous improvements in waste recycling and resources recovery may be achieved via research on new approaches and technologies, including biotechnology to address process waste. Recycling to a very high degree will be needed to achieve more continuous processes and closed systems. The technologies developed will have to lead to this end.

Environmental Engineering — Innovative technologies are needed to eliminate or combine process steps in order to capture and utilize wastes. Energy reduction processes will have to be driven by the impact on environment. In the light of increasing environmental regulations and decreasing landfill space, future technologies will strive to achieve zero emissions and waste. Use of steel plant slag in cement manufacture and road building are examples. Development of other ways to use slag could be an area of interest. Processes for recycling and disposal of low-level radioactive waste could be a boon to the industry.

Lean and flexible manufacturing systems, which eliminate waste and non-value-added activities, will be used in the future. The emphasis in these new processes will be to avoid pollution rather than to control and treat it. NO_x generation from by-product fuels used in steelmaking (e.g., blast furnace gas, coke oven gas) is higher than predicted and is not well understood. This area should be investigated to provide the foundation for developing burners and/or operating procedures that pollute less.

STEEL INDUSTRY VISION OF THE FUTURE

Product Development — Future product demands will tend to vary drastically and at a fast rate. As such, technology development will have to provide adaptability and flexibility of processes. Constant drive for increased quality and optimized end use of the material will dictate the type of technology. Ability to use a variety of feedstocks to achieve the required final specifications in a most cost-effective manner will determine the suitability of a technology.

Developments in the areas of low tramp elements in the products could lead to a high demand, since disposal of the prompt scrap and postconsumer scrap would pose no problem. Technologies for near-net-shape products will result in cost reduction. High-performance products with close tolerances and superior properties will be in demand. Also, steel products will have to beat competitive materials in properties, cost, and performance. Overall, the technologies and products will have to meet the changing demands of customers.

Industry-Government Partnership

The American Iron and Steel Institute (AISI) and the Steel Manufacturers Association (SMA), which represent nearly all U.S. (and North American) steel-manufacturing companies, have worked together to identify the critical areas and targets of opportunity where continuous improvement will be necessary to retain steel's position as the material of choice for the 21st century. On May 22, 1995, DOE signed an R&D compact to create a voluntary collaborative R&D partnership with the industry. The partnership will involve the demonstration, evaluation, and acceleration of new technologies and scientific insights that address several specific and crosscutting needs in production efficiency, recycling, and environmental engineering.

Steel Technology Roadmap

Representatives from AISI and SMA are developing a technology roadmap that defines a strategy for pursuing and achieving the goals set out in the vision. AISI and SMA are working with industry and research institutions, including universities and National Labs, to develop the roadmap. OIT's Steel Team is facilitating this effort. The roadmap process will identify key RD&D activities that meet the industry's vision, and projects will be selected based on the roadmap. OIT will then solicit, review, and select proposals from organizations based on their technical expertise and partnership or collaboration between industry and government.

Implementation of the Vision

Working with AISI and SMA, OIT's Steel Team will conduct two solicitations: one will be for industry, with universities and National Labs as partners; the second will be for National Labs. In both solicitations, a panel of reviewers representing industry will select and prioritize proposed R&D projects based on industry needs identified in the technology roadmap. The industry solicitation will support R&D projects led by steel industry vendors or end-users to develop equipment and processes that address the industry's technology needs. The National Lab solicitation, on the other hand, will fund activities that enable lab-generated technology to be adapted to meet the industry's needs.

DOE Steel Industry-Related R&D, FY 96

Relationship	Funding (million \$)	Number of Projects
Direct	6.6	14
Indirect	31.4	136
Total	38.0	150

Source: IPLocator database

The Steel Industry's Vision for the 21st Century

The steel industry has set this "vision" for itself:

- Steel will be the material of choice for the 21st century. The industry will be a strong, vibrant sector of the economy, providing high-quality, value-added products to a wide array of customers in an environmentally friendly, cost-effective manner. It will continue to be globally competitive both in quality and cost. It will lead the world in innovation and technology.
- Steel production from recycled scrap will increase to over 70%.
- Today the steel industry produces over 8 million tons/year of iron and carbon-bearing wastes. Approximately 50% of these are sold or recycled at a fraction of their true value, and the remaining 50% is landfilled. In the future, all of these will be recycled in a direct smelting process that recovers their full value.

SELECTED OIT STEEL INDUSTRY R&D PROJECTS

STEEL PLANT DUST AND SLUDGE (WASTE OXIDE) RECYCLING

Waste by-products are generated at a number of sites within the steel mill, including the coke ovens, blast furnace, BOF, and hot rolling mill. Blast furnace ironmaking generates dust that is removed by a dust catcher and a wet scrubber. The wet scrubber produces an effluent that, after treatment, produces a fine-particle, sometimes oily sludge. Similarly, the BOF process usually has an emission control system that removes fine oxides (in the form of dust) from BOF off-gas. An iron oxide sludge is produced in the hot rolling mill. This sludge must be removed in a wastewater treatment system. For years, these by-products have been landfilled on-site with the hope that reclamation would become economically feasible at some point in the future.

That point looms much nearer with the initiation of a project to develop a process for recycling blast furnace and BOF dust and sludge, and rolling mill sludge. The new process uses a smelter, a completely enclosed melting vessel. The molten pig iron is processed in the BOF. It is anticipated that more than 3.5 million tons of sludge and dust will be recycled each year with the smelter process, greatly reducing land-filling of these wastes.

PARTNERS:	AISI, Mannesmann Demag
OIT COST:	\$5,635,000
INDUSTRY COST-SHARE:	\$2,624,000
ENERGY SAVINGS:	13.3 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	5.8 million tons waste/yr in 2010
COST SAVINGS :	\$427 million/yr in 2010
CONTACT:	Gobind Jagtiani (202-586-1826)

ELECTROCHEMICAL REMOVAL OF ZINC FROM STEEL SCRAP

Galvanizing is a process in which steel parts, such as those used in auto bodies, are coated with zinc to prevent corrosion. The high quality of galvanized steel makes this scrap a valuable feedstock for both steelmaking and foundry operations. Unfortunately, the zinc coating on galvanized steel scrap causes severe operating and environmental problems and has a deleterious effect on product quality. The electrochemical dezincing process being developed not only removes this zinc but recovers it for reuse, potentially reducing U.S. zinc imports while producing clean scrap.

Electrochemical dezincing takes place in a large tank. The scrap is then washed and shipped to a steel mill or foundry. Energy is saved because the energy required to dezinc scrap is about 20% of that for producing molten iron, the conventional steelmaking furnace feedstock. Environmental benefits of the process include elimination of both baghouse dust and zinc contamination in waste water associated with the melting of galvanized scrap. The consumption of galvanized steels has roughly doubled since 1980 and is expected to continue growing at a steady rate.

PARTNERS:	Argonne National Laboratory, Metal Recovery Industries U.S.
OIT COST:	\$1,400,000
INDUSTRY COST-SHARE:	\$1,453,000
ENERGY SAVINGS:	65.9 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	14.3 million tons waste/yr in 2010
COST SAVINGS :	\$145 million/yr in 2010
EMPLOYMENT:	2,360 jobs (new base) in 2010
CONTACT:	Harvey Wong (202-586-9235)

SELECTED OIT STEEL INDUSTRY R&D PROJECTS

ADVANCED PROCESS CONTROL RESEARCH PROGRAM FOR THE STEEL INDUSTRY

One of OIT's steel R&D programs is developing new and improved methods of measuring steel-processing parameters and steel properties from production through casting and forming into finished products. Being able to more accurately measure properties such as temperature, composition, and strength can help steelmakers optimize their processes to yield the highest possible quality steel and steel products as efficiently and with the least environmental impact as possible.

The Advanced Process Control R&D program includes several projects, including each of the following five projects.

PARTNER:	AISI
OIT COST:	\$7,707,000
INDUSTRY COST-SHARE:	\$3,303,000
ENERGY SAVINGS:	23.7 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	1.9 million tons waste/yr in 2010
COST SAVINGS:	\$307 million/yr in 2010

OPTICAL SENSORS AND CONTROLS FOR IMPROVED R&D OPERATIONS

In the absence of up-to-the-minute data on what's really happening inside the BOF during steelmaking, steelmakers tend to leave the molten steel in the furnace longer than necessary and tap at lower carbon levels. Two new optical sensors are being developed that could change this practice: one for real-time measurement of the composition and temperature of BOF off-gases and one for measuring the temperature of the steel bath. Both of these sets of valuable process information will be used to develop a new BOF control strategy to allow the molten steel to be tapped at a lower temperature and precise carbon levels, reducing processing time and increasing furnace productivity.

PARTNERS:	Sandia National Laboratories, Bethlehem Steel, Insitac Measurement Systems, Timken
CONTACT:	Joe Vehec (412-566-2326)

MICROSTRUCTURE ENGINEERING FOR HOT STRIP MILLS

In hot rolling, semifinished steel shapes are reheated and rolled into strip and other final products. Some steel alloys are difficult to hot roll because the desired properties of the final product must be tightly controlled. These properties depend on the exact design and operating conditions of the hot strip mill. A new computer model is being developed to help steelmakers predict the thermal and microstructural evolution of steel during hot rolling, as well as predict the final product properties, based on mill design and operating practices. Linking the properties of hot-rolled products to the process parameters of the mill will yield higher quality steel with far fewer rejects, thus increasing yield and reducing production costs.

PARTNERS:	National Institute of Standards and Technology, University of British Columbia
CONTACT:	Joe Vehec (412-566-2326)

SELECTED OIT STEEL INDUSTRY R&D PROJECTS

ONLINE MECHANICAL PROPERTIES MEASUREMENTS

After steel strip is hot rolled, it is cold rolled to improve the metal's ductility, and then heat treated to correct the deformation that occurred during cold rolling. The most common form of heat treatment is annealing. Because properties of annealed steel are currently measured only in the front and tail of the strip, the quality of annealed products sometimes suffers. New online sensors currently under development – one magnetic and one laser-ultrasonic – are being investigated as a means of measuring mechanical properties of interest throughout the strip, thus ensuring higher quality and less time spent reprocessing out-of-spec strip.

PARTNERS: Industrial Materials Institute, LTV Steel, Weirton Steel, NIST

CONTACT: Joe Vehec (412-566-2326)

PHASE MEASUREMENT OF GALVANNEAL

Galvannealed steel sheets are coated with a mixture of zinc and iron to improve corrosion resistance, weldability, and paintability for products such as auto body panels. A critical factor in making galvannealed sheet is the microstructure of the zinc-iron coating, which currently can only be measured offline in the laboratory. This means that any necessary adjustments to control the microstructure cannot be made quickly enough to benefit all of the sheet being processed. Any sheet that does not meet the required specs must be reprocessed, wasting time, materials, energy, and money. An online X-ray instrument for determining microstructure is being developed that will greatly reduce the time lag between measurement and corrective action.

PARTNERS: Data Measurement, Jet Propulsion Laboratory, Inland Steel, Stelco

CONTACT: Joe Vehec (412-566-2326)

TEMPERATURE MEASUREMENT OF GALVANNEAL

In another effort aimed at improving galvannealing operations, a new noncontact method of measuring the temperature of the sheet as it exits the galvannealing furnace is being developed. This new technique is based on phosphor thermography, in which a phosphor compound is applied to the surface of the strip and illuminated with a laser or ultraviolet light. This online measurement will provide faster feedback on galvanneal product quality, thus reducing product variability and rejection rates. In the long term, it is hoped that this sensor, together with the microstructure sensor described above, will allow galvannealing properties to be measured in real time, with no time lag between taking the measurement and getting the result.

PARTNERS: Oak Ridge National Laboratory, National Steel

CONTACT: Joe Vehec (412-566-2326)

THE ALUMINUM INDUSTRY

Economics and Competitiveness

Aluminum possesses numerous useful properties, including high strength and light weight, corrosion resistance, electrical conductivity, and recyclability. In addition, the natural resources required to make it (mainly bauxite) are abundant on a world-wide basis, and the costs of producing the metal are relatively low. These factors contribute to several mass markets. Major aluminum markets include beverage cans, motor vehicles, aircraft, power transmission cables, and construction applications such as siding and doors.

The United States is the world's largest producer and consumer of aluminum metal and products. Industry shipments in 1993 of an estimated 8.2 million metric tons of product (up from about 7.1 million tons in 1980) were valued at about \$21 billion. This U.S. industry is divided into several major segments: alumina refining, primary metal smelting, secondary (recycled) metal smelting, semifabricated products, and finished products. The primary segment produces aluminum from bauxite and other alumina raw materials, whereas the secondary segment recovers aluminum from scrap.

The aluminum industry employs about 72,000 workers in the smelting and fabrication phases of its operation. In addition, the aluminum industry supports thousands of workers in alumina plants, recycling, and foundries. Wages of aluminum industry workers are about 41% above the average for all domestic industries.

Low energy costs for recycling, together with growing concerns over solid waste disposal, have contributed to substantial growth in aluminum recycling in the United States. In 1960, about 400,000 metric tons of aluminum were recycled; by 1994, the corresponding figure was 3.1 million metric tons. In 1992, there were about 68 secondary aluminum smelters in the United States, employing more than 3500 workers. Secondary

smelters are mostly located near major industrial and consumer centers, such as Southern California and the Great Lakes region, which generate large quantities of scrap metals.

As late as the mid-1960s, the United States accounted for 40% of world aluminum production. However, by the 1980s, changing business conditions and a highly competitive world market forced the U.S. aluminum industry into a major restructuring. Between 1987 and 1992, U.S. firms closed about 1.1 millions tons of high-cost U.S. smelting capacity (nearly 25% of the U.S. total) to lower their average domestic production costs to more competitive levels. U.S. smelter closures, combined with expanded capacity in other countries, meant that by 1994 the U.S. share of world aluminum production had declined to about 17%.

As domestic firms have lowered their presence in the smelting end of the business at home, they have increased their investment in the fabrication end of the industry and boosted substantially their recycling of used beverage cans as a way of further reducing their average costs of production. In addition, they aggressively pursued larger shares of the automobile and packaging markets through joint ventures and foreign investment.

Table 3-2. Aluminum Industry Profile

Value of Shipments	\$21.5 billion
Total Employment	71,800 jobs
Capital Expenditures	\$593 million
Net Trade Balance	(\$3.0 billion)
Energy Consumption	0.4 quadrillion Btu
Pollution Control Costs	\$283 million
Average Hourly Earnings	\$15.45

Figure 3-5. International Comparison of Per Capita Aluminum Use, 1994

Source: The Aluminum Association

Figure 3-6. Aluminum Industry Share of GDP

Source: DIT estimates from Department of Commerce data

THE ALUMINUM INDUSTRY

Energy

The primary aluminum industry has one of the highest energy intensities of any manufacturing process. In 1994, the industry spent \$1.7 billion on energy, or about 8.1% of the value of its total shipments. For primary production, the costs were \$1.25 billion — about 24% of the value of shipments but equal to about one-third of industry operating costs. The U.S. aluminum industry annually consumes approximately 1 quad of primary energy. Smelting operations account for 70% of energy use for primary aluminum, and refining accounts for 15%. The main sources of this energy are hydroelectric power and coal.

Overall aluminum energy efficiency has improved about 20% over the last two decades, and on average it currently takes about 6.5 kWh to produce 1 pound of aluminum. The average total energy used (including power generation heat losses) to make a ton of aluminum is nearly 180 million Btu. Secondary aluminum requires as little as 5% as much energy to produce, which makes the economic attractiveness of recycling favorable.

Environment

Although aluminum manufacture is not as environmentally stressful as processes used to produce a number of other materials, it still contributes to a variety of environmental problems. Roughly 50 to 70 pounds of spent potliner, or insulating brick, are generated for each ton of aluminum produced. The spent potliner contains fluoride, sodium, and cyanide contaminants and is listed as a hazardous waste. The production of aluminum also creates fluoride emissions, which must be controlled. The reaction in the electrolytic cell creates carbon dioxide.

Emissions also come from the production of electricity and from producing carbon anodes. Each year about 2 billion pounds of black aluminum dross and saltcake generated by the aluminum recycling industry are landfilled. Finally, the extraction of alumina from bauxite produces 2 pounds of gangue per pound of alumina and wastewater during the calcination process.

Somewhat offsetting the environmental problems that the aluminum industry faces are a variety of environmental benefits that the metal affords its consumers. For example, the light weight of aluminum may enable automobile manufacturers to reduce considerably the average weight of autos produced in this country. This, in turn, could help trim both gasoline use and the carbon dioxide and other emissions associated with the combustion of auto fuels.

The inherent recyclability of aluminum offers numerous environmental benefits, too. In addition to saving up to 95% of the energy needed to manufacture primary aluminum, recycled aluminum conserves natural resources; lowers emissions of hydrogen fluoride, carbon dioxide, sulfur dioxide, nitrogen oxide, and carbon fluoride; and reduces the generation of waste materials. Such favorable life-cycle attributes of aluminum have contributed to a sixfold increase in recycling of the metal over the last 30 years.

Figure 3-7. Primary Aluminum Production Processes and Energy Flows

Figure 3-8. Growth in Scrap Recycling as Percent of U.S. Aluminum Production

Source: The Aluminum Association

ALUMINUM INDUSTRY VISION OF THE FUTURE

The aluminum industry and DOE are working together to build a stronger and more competitive aluminum industry. The industry-government partnership will also help to achieve national goals for energy efficiency, economic growth, and the environment through the development and application of innovative technologies.

Industry Vision

In March 1996, the Aluminum Association published "Aluminum Industry: Industry-Government Partnerships for the Future." This report articulates the industry's vision of its future and defines specific needs in a wide variety of precompetitive research areas. The formation of research partnerships to address these challenges should enable the U.S. aluminum industry to hold its position of global technological leadership into the 21st century and maintain its strong contribution to the U.S. industrial base.

A fundamental goal of the industry's vision is to quantitatively define and better understand and control all phases of its flow sheet from alumina processing to microstructure performance. This will allow the industry to provide the ecologically sustainable, high-performance materials and systems needed to expand its markets well into the 21st century. To accomplish its goals, the industry will need to maintain scientific and engineering leadership in the following six areas:

- Energy efficiency
- Manufacturing processes and technologies
- Ecological sustainability
- Enabling technologies
- Information technologies
- Computational materials

In order to maintain global leadership in these areas, the industry has determined that it will need to focus its R&D in three major areas, including:

- Raw materials and semifabrication production technology
- Manufacturing and enabling technology
- Application technology

See page 48 for details.

ALUMINUM CAN STOCK BEING COILED AT ROLLING MILL.
Source: The Aluminum Association

Industry-Government Partnership

The aluminum industry, represented by the Aluminum Association, signed a voluntary cooperative agreement with Secretary of Energy Hazel O'Leary in October 1996. The agreement establishes a framework for joint R&D activities between the aluminum industry and the Federal Government. The compact signed by the industry and DOE will facilitate the creation of R&D partnerships, consortia, or joint ventures with customers, suppliers, academia, and government labs and further leverage the formidable strengths and capabilities of these institutions.

For its part, OIT has realigned its existing aluminum manufacturing, recycling, and fabrication R&D programs to address the technology needs identified in the industry's vision document. In addition, OIT has budgeted \$2 million in FY97 to support research projects under Aluminum Vision Partnerships.

ALUMINUM INDUSTRY VISION OF THE FUTURE

Technology Roadmap

Potential Areas for R&D Partnerships

"Aluminum Industry: Government Partnerships for the Future" identified a number of potential areas of cooperative research, including:

Raw Materials and Semifabricated Production Technology

- Enhanced alumina technology
- 1 mega-amp Hall-Heroult cell
- Improved anode/cathode materials and controls
- Continuous online sensors
- Alternative smelting technologies
- Strip/spray casting optimization
- Aluminum powder optimization
- Extrusion process optimization
- Alloy optimization
- Advanced process controls
- Shop-floor hardened sensors
- PFC minimization via pot control technologies
- Cost-effective retrofit of Soderberg reduction cell
- Skim/dross processing
- Saltcake treatment/recovery
- PCB remediation and biostabilization

Manufacturing and Enabling Technology

- Near-net-shape technologies
- Enhanced joining technology
- New forming technology
- New/optimized coating technologies

Application Technology

- Aluminum earthquake-resistant structures
- Improve aluminum bridge design
- New infrastructure applications
- Optimize aluminum battery technology
- Technology for lightweight passenger auto
- Expansion of life-cycle cost programs

In August 1996, the aluminum industry began work on its technology roadmap. The roadmap will identify current technologies and barriers, options and pathways. It will also set technology priorities and help establish a research agenda. The roadmap is meant to facilitate achievement of the aluminum industry's strategic vision as described in "Aluminum Industry: Industry-Government Partnerships for the Future."

To construct the roadmap, the Technical Advisory Committee from the Aluminum Association will first develop industry-wide performance targets. These targets will define specific goals for reducing energy use, improving productivity, and improving environmental quality for each of the industry's principal segments, including raw materials, semifabricated products, and finished products. DOE and the aluminum industry — together with representatives from DOE's National Labs, academia, and other stakeholders — will then meet in a two-day workshop to define a portfolio of short-, medium-, and long-term technologies needed to achieve the goals. A draft of the technology roadmap will be presented for peer review at several forums in early 1997, including the annual meeting of The Materials Society (February 1997); OIT's Expo (February 1997); and Alumitech 97, in May.

DOE Aluminum Industry-Related R&D, FY 96

Relationship	Funding (million \$)	Number of Projects
Direct	8.3	10
Indirect	14.3	107
Total	22.6	117

Source: IPLocator database

Figure 3-9. U.S. Aluminum Industry Markets, 1994

Total = 20.6 billion pounds

Source: The Aluminum Association

SELECTED OIT ALUMINUM INDUSTRY R&D PROJECTS

INERT ANODE/CATHODE SYSTEM FOR ALUMINUM SMELTING

For the past 100 years, all primary aluminum in this country has been produced in Hall-Heroult electrolytic cells that pass an electric current through alumina to convert it to aluminum metal. Each electrolytic cell has an anode typically made of carbon and a cathode consisting of molten aluminum. These types of anodes and cathodes are far from ideal from an operating perspective, however. The carbon in the anodes is consumed during the conversion process, forcing them to be replaced about every two to three weeks. In addition, the undulating surface of the molten aluminum in the cell creates a large gap between the anode and the cathode to prevent short-circuiting of the cell. Unfortunately, this gap makes the cell consume much more electricity than is actually needed to convert the alumina. The combination of an inert (nonreacting) anode, which would not be consumed during the electrolytic process, and a cathode whose surface would remain stable (unlike the sloshing molten aluminum) would allow the cell to operate with a much narrower anode-cathode gap while reducing downtime for anode replacement.

The combined efforts of a number of research organizations have resulted in the development of inert titanium diboride and graphite (TiB₂-G) cathodes and inert anodes composed of a ceramic-metal composite material.

PARTNER:	Alcoa
OIT COST:	\$6,078,000
INDUSTRY COST-SHARE:	\$1,569,000
ENERGY SAVINGS:	104 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	7.1 million tons waste/yr in 2010
COST SAVINGS:	\$587 million/yr in 2010
EMPLOYMENT:	10,220 jobs (new base) in 2010
CONTACT:	Sara Dillich (202-586-7925)

The anticipated benefits of retrofitting a Hall-Heroult cell with the new inert anode/cathode system include

- Potential to conserve up to 20% of the total energy currently used in the cell itself and in the production of conventional carbon anodes
- Nearly 10% reduction in the cost of aluminum production
- Up to 25% increase in productivity, allowing production to be increased using the same number of cells

SPRAY FORMING OF ALUMINUM

The production of aluminum sheet for use in cars, airplanes, and other applications consists of a series of individual operations that are far from optimal from the standpoint of energy, productivity, and materials. The main culprit is ingot casting, in which molten aluminum is poured into molds, cooled until it hardens, and then removed from the molds and reheated for rolling or other processing. Spray forming of aluminum is being developed as an exciting new alternative to this inefficient series of steps. In spray forming, the molten aluminum is converted into aluminum droplets, which are then sprayed continuously onto a base form that is conveyed through a controlled-atmosphere chamber. The rapidly cooling film is then rolled or otherwise processed just as an ingot would be. The new process has fewer steps, simplifying production and eliminating the wasteful reheating step required with ingot casting.

Spray-formed materials have been determined to be metallurgically superior to those made from ingots in terms of corrosion resistance, strength, and toughness. The new process enables the microstructure of the aluminum products to be more closely controlled, which will enhance the process's ability to use recycled aluminum without degrading new product properties. Other benefits include

- Energy savings of as much as 15%
- Cost savings of several percent
- Reduction in NO_x, SO_x, and other emissions

PARTNERS:	Alcoa, Air Products and Chemicals, Idaho National Engineering Laboratory, University of California-Irvine, Carnegie Mellon University, Mannesmann Demag
OIT COST:	\$3,097,000
INDUSTRY COST-SHARE:	\$1,559,000
ENERGY SAVINGS:	31.7 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	2.0 million tons waste/yr in 2010
COST SAVINGS:	\$183 million/yr in 2010
EMPLOYMENT:	1,290 jobs (new base) in 2010
CONTACT:	Sara Dillich (202-586-7925)

It is anticipated that spray forming will expand the use of aluminum parts in cars, airplanes, and other markets because of the high-quality alloys that it can produce.

SELECTED OIT ALUMINUM INDUSTRY R&D PROJECTS

ENERGY EFFICIENT CALCINER

Calcination — heating at a high temperature — is the last step in the production of alumina from bauxite ore. In the calcining step, water is removed from the alumina to prepare it for processing in the Hall-Heroult electrolytic cell. The current alumina calcination process relies on high temperatures to force out the water; a new process is being developed, however, that relies on the combination of high pressure and temperature to dry the alumina. Because there are two driving forces instead of one in the new process, the calciner can be operated at a lower temperature, thus saving energy. In addition to energy savings of 4 trillion Btu annually, the new calciner will produce alumina that has improved physical properties over alumina from a conventional calciner. The size of the alumina particles will be more uniform, and they will produce less dust and therefore require simpler environmental controls. The new calciner system is designed to enable steam from the process to be recovered for process use within the plant.

PARTNER:	Alcoa
OIT COST:	\$905,000
INDUSTRY COST-SHARE:	\$388,000
ENERGY SAVINGS:	4.2 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	17.7 million tons waste/yr in 2010
COST SAVINGS:	\$13.1 million/yr in 2010
EMPLOYMENT:	140 jobs (new base) in 2010
CONTACT:	Sara Dillich (202-586-7925)

ALUMINUM SALTCAKE

Saltcake, a by-product of aluminum melting operations, consists of aluminum, salts, and residue-oxide (nonmetallic product, or NMP). The conventional method of saltcake recycling includes crushing and screening to recover the entrained aluminum, dissolving the soluble salts in water, filtering to recover the NMP, and recovering the salts by evaporation of the process brine. This process is energy and cost-intensive and cannot compete economically with landfilling of the saltcake.

With support from OIT, Argonne National Laboratory is developing economical new processes for the recovery of salt from process brines, the largest obstacle to cost-effective saltcake recycling. In addition, Argonne is developing processes that convert NMP to high-value-added products, such as ceramic fiber insulation, abrasives, and refractory aggregate for high alumina refractories. Pilot-scale experiments using electrodialysis, the most promising recovery technique identified, are under way, as is a multi-industry project to develop a process to convert NMP to refractory aggregate.

PARTNERS:	Argonne National Laboratory
OIT COST:	\$2,823,000
INDUSTRY COST-SHARE:	\$1,350,000
ENERGY SAVINGS:	8.0 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	0.8 million tons waste/yr in 2010
COST SAVINGS:	\$34 million/yr in 2010
EMPLOYMENT:	480 jobs (new base) in 2010
CONTACT:	Sara Dillich (202-586-7925)

INNOVATIVE VERTICAL FLOTATION MELTER

Recycling is a critical component of the U.S. aluminum industry, both from its contribution to the environment and because of the favorable economic impact on production. The amount of recycled aluminum doubled in the last 10 years, growing to one-third of the total U.S. aluminum supply. Recycled aluminum is typically melted in gas- or oil-fired reverberatory furnaces, which generate substantial emissions.

The vertical flotation melter being developed with support from OIT represents a significantly cleaner and more efficient alternative for processing aluminum scrap. In the new process, the scrap is first dried and de-coated in a rotary kiln dryer. It is then melted in the vertical flotation melter, where particles of varying sizes are kept in suspension for a specified period before falling into the molten metal bath below. In addition to fuel savings and emissions reductions, the new process will reduce fines and conserve valuable by-products. The melter also has applications in the glass and steel industries.

PARTNERS:	Energy Research; Stein, Atkinson and Stordy; Gillespie and Powers, IMCO Recycling
OIT COST:	\$237,000
INDUSTRY COST-SHARE:	\$322,000
ENERGY SAVINGS:	35 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	125 thousand tons waste/yr in 2010
CONTACT:	Ramesh Jain (202-586-2381)

THE METAL CASTING INDUSTRY

Economics and Competitiveness

The U.S. metal casting industry is at the foundation of virtually every manufacturing industry in the country. Using primarily scrap metal, U.S. metalcasters create literally tens of thousands of intricately shaped metal parts used in wide-ranging applications. Metal casting is the process of pouring or injecting molten metal into a mold cavity, allowing it to cool and solidify, and then releasing it from the mold.

In many respects, metal casting complements the U.S. primary metals industries. The steel and aluminum industries typically produce a limited number of commodities — such as sheet, tubes, bar, or wire — from mostly virgin materials. They are typically capital intensive, scale-economy industries which tend to be located near their energy or raw material suppliers. Metal castings, on the other hand, are produced from the scrap largely unusable by the primary metal industries. Foundries produce a much more diverse line of highly specialized products which tend to be more labor intensive. Foundries also tend to locate closer to their customers and markets.

Metal castings are used in the assembly of more than 90% of all durable goods and in virtually 100% of machine tools, manufacturing machinery, and similar industrial equipment. In 1994, the U.S. market for metal castings was estimated to be \$23 billion. When machined, castings are used as components in products ranging from motor vehicles and aircraft to appliances and power tools. Most homes contain more than a ton of cast pipe, bathtubs, sinks, fixtures, hardware, and furnace and air-conditioning parts.

Table 3-3. Metal Casting Industry Profile

Value of Shipments	\$22.7 billion
Total Employment	205,000 jobs
Capital Expenditures	\$966 million
Net Trade Balance	(\$24 million)
Energy Consumption	0.2 quadrillion Btu
Pollution Control Costs	\$381 million
Average Hourly Earnings	\$13.12

Moreover, to properly appreciate the role of metal casting in our industrial infrastructure, it must be recognized that foundries are major consumers of waste materials. Scrap iron and steel are the major source of raw materials for foundries, accounting for about 85% of all ferrous castings produced in the United States. Reclaimed copper, aluminum, lead, tin, zinc, and other metals are also extensively recycled in making non-ferrous castings.

The U.S. metal casting industry is composed of more than 3100 foundries employing about 205,000 workers. An important demographic characteristic of the metal casting industry is the fact that about four out of five foundries employ fewer than 100 workers. Fewer than 10% have more than 250 employees. Foundries are located throughout the United States with the highest concentration in the Midwest.

In 1994, estimated world production of castings reached 55.6 million tons, with the U.S. metal casting output around 13 million tons, 20% of the world total. The U.S. total includes 11 million tons of ferrous castings and 2 million tons of non-ferrous castings valued at \$14 billion and \$9 dollars, respectively.

Figure 3-10. Changes in Metal Casting Production by Type, 1972-1994

Table 3-4. Metal Casting Industry Employment, 1994: 10 Largest States

State	Employment
Ohio	28,200
Wisconsin	20,900
Michigan	19,400
Indiana	15,100
Pennsylvania	13,900
Illinois	12,000
Texas	10,600
California	10,300
Alabama	8,700
Tennessee	7,000

THE METAL CASTING INDUSTRY

Energy

The U.S. metal casting industry consumed about 250 trillion Btu of energy in 1988 while producing 12.4 million tons of product, yielding an average energy use of about 20 million Btu for each ton of product shipped. About 55% of the metal casting industry's energy requirements are for melting. Energy expenditures (66% natural gas and 34% electricity) totaled \$1.1 billion in 1994, about 5% of the value of shipments that year.

Figure 3-11. Metal Casting Energy Expenditures, 1980-1994

Source: Bureau of the Census

Environment

Sandcasting produces more than 100 million tons of spent sand annually. This sand is recycled until it breaks down and can no longer be recycled, yielding about 8 million tons of spent sand each year. Currently, more than 80% of the spent sand is land-filled. This equates to about 850 pounds of spent sand for every ton of ferrous metal shipped from a foundry (the amount increases for copper and aluminum). Ferrous foundries also dispose of about 350 pounds of slag per ton of casting, and more than 200 pounds of emission control dust per ton of casting. About 4% of the industry's waste is hazardous. Examples of hazardous waste include sand from brass foundries, dusts and sludges, and quench dropout containing toxic heavy metals. In addition, about 5% of all castings produced are recast because they are of poor quality.

Annual operating costs related to pollution abatement are more than \$300 million to comply with environmental regulations. Measures under the Clean Air Act Amendments of 1990 are anticipated to add another \$750 million to the annual costs. Smaller foundries find it difficult to invest in pollution control equipment, which represents about 30% to 40% of all capital expenditures.

Recycling and reuse have always been an integral element of the U.S. metal casting industry. The main feedstock of many foundries is scrap, which is remelted and formed into new useful products. Recycling has shown to generate both economic and environmental benefits to the metal casting industry. Each year the industry as a whole recycles between 15 and 20 million tons of scrap materials. This represents an approximate cost savings to the industry of \$3.5 billion.

Figure 3-12. Metal Casting Pollution Control Cost Trends

Source: Bureau of the Census

METAL CASTING INDUSTRY VISION OF THE FUTURE

The metal casting industry and OIT are working together to build a stronger, more competitive metal casting industry. The goal is to develop partnerships involving the Federal Government and industry to achieve a common vision for improving productivity, energy efficiency, and competitiveness.

Industry Vision

In September 1995, chief executive officers and presidents from the foundry, diecasting, and foundry supply industries co-authored "Beyond 2000: A Vision for the American Metal Casting Industry." Development of the vision illustrates the commitment of industry members to joining forces in order to increase the global competitiveness of the metal casting industry. The vision lays out a framework for addressing industry needs in six critical areas:

- Production efficiency
- Recycling
- Pollution prevention
- Application development
- Process control
- New technology development

The vision identifies a metal casting industry goal of being the preferred supplier of near-net-shape or net-shape metal components beyond the year 2000. Other goals of the industry include

- Increasing market development activities to improve market share in current markets by 10%, recapture 25% to 50% of lost markets, and increase the rate of new market development
- Developing materials technologies that improve the variety, integrity, and performance of cast metal products
- Developing advanced manufacturing technologies to increase productivity by 15%, reduce average lead times by 50%, and reduce energy consumption by 3% to 5%
- Achieving 100% pre- and postconsumer recycling, 75% beneficial reuse of foundry by-products, and the complete elimination of waste streams
- Renewing emphasis on human resources, education, and training; attracting talented individuals into the industry and improving the training of employees in the latest technologies and techniques
- Increasing by 10% industry reinvestment in research, education, and marketing programs

HOT MOLTEN METAL POURS FROM A FURNACE.

- Encouraging partnerships that combine the experience, resources, and knowledge available in public and private sector organizations

Industry-Government Partnership

Representatives from three major metal casting industry societies — the American Foundrymen's Society (AFS), the Steel Founders' Society of America (SFSA), and the North American Die Casting Association (NADCA) — signed a voluntary cooperative agreement with Secretary of Energy Hazel O'Leary in October 1995. The agreement sets forth a framework for identifying appropriate areas of joint RD&D between the U.S. government and the metal casting industry. Projects identified by this research partnership will be carried out in a joint Federal-industry program designed to develop technologies for industry customers. The program will be guided by collaborations among industry, metal casting associations, Federal agencies, universities, National Labs, and other major research institutions with expertise in the metal casting industry.

Technology Roadmap

The Cast Metals Coalition (CMC; see box on page 54) is developing a technology roadmap that defines a strategy for pursuing and achieving the goals set out in the vision. CMC is working with industry and research institutions, including universities and National Labs, to develop this roadmap. OIT's Metal casting Team is facilitating this effort.

Metal Casting RD&D projects will be selected based on the metal casting technology roadmap. The CMC will operate with input and guidance from industry, academia, OIT, and other

METAL CASTING INDUSTRY VISION OF THE FUTURE

The Cast Metals Coalition

The Cast Metals Coalition (CMC) was formed in 1991 and is composed of industry experts from the American Foundrymen's Society (AFS), the Steel Founders' Society of America (SFA), and the North American Die Casting Association (NADCA). These societies directly represent over 1400 metal casting organizations and indirectly support and provide assistance to more than 2000 metalcasters. The CMC is led by the South Carolina Research Authority (SCRA), a recognized leader in consortia and distributed management operations, with strong experience working in the metal casting area.

Through an Executive Board and several technical committees, the CMC operates with input and guidance across the metal casting industry, drawing on the existing metal casting Industrial Advisory Board and numerous technical committees in the metal casting associations. It also relies on the input and advice from corporations, academia, and government agencies. The CMC technical committees develop candidate R&D projects from the goals and objectives identified in the metal casting vision, which was developed in 1995 by the industry.

The CMC Executive Board is composed of representatives from the three associations, the OIT, and the Metal Casting Industrial Advisory Board. These individuals work together to ensure that the candidate R&D projects correspond to the vision's objectives and goals, and make the final selection.

The CMC is structured as an open and interactive process to address the vision and the requirements established by the metal casting industry. All segments and representatives of the industry have equal access to potential sponsors and funding to achieve the industry's vision plans and goals.

government agencies to develop candidate RD&D projects. The CMC will identify key RD&D activities that align with the industry's vision. It will also solicit, review, and select proposals from organizations. The review process will assess expertise and demonstrated collaboration between industry and Government. Once a project commences, the CMC will manage the project and evaluate its progress. In addition, OIT will provide guidance in project selection through a technical committee made up of representatives of CMC, industry, and OIT.

Implementation of the Vision

OIT's Metal Casting Team facilitates implementation of the metal casting industry roadmap through the CMC. CMC provides the structure and facilitates the teamwork needed for review and cost-shared funding of R&D efforts. It also helps ensure that funding targets the most critical needs of industry with a balanced portfolio of near- and long-term research activities. In addition, DOE's Metal Casting Industrial Advisory Board, composed of nine senior members of the metal casting industry, provides third-party oversight of the OIT-CMC coalition.

The CMC selection process draws on the identified requirements of both industry and DOE to focus funding on critical research areas. Industry technical and research boards review all proposed CMC efforts, and final technical clearance comes from joint CMC-DOE and Industry Advisory Board review.

Figure 3-13. Metal Casting End-Use Markets, 1994

DOE Metal Casting Industry-Related R&D, FY 96

Relationship	Funding (million \$)	Number of Projects
Direct	3.0	22
Indirect	40.5	149
Total	43.5	171

Source: IPLocator database

SELECTED OIT METAL CASTING INDUSTRY R&D PROJECTS

ADVANCED LOST FOAM TECHNOLOGY

Lost foam casting is a form of investment casting, where each mold can only be used a single time. For many years, metal casting industry experts felt that technology advancements in lost foam casting could have significant benefits to the industry. Lost foam casting is a simple, cost-efficient process that offers design flexibility and can easily be automated to improve its productivity. This type of casting is typically used for complex castings weighing 30 pounds or less, such as those required by the electronics, defense, and aerospace industries.

The research being conducted at the University of Alabama-Birmingham is focused on advancing the theory and application by increasing the range of plant experiments and types of metals. This project is a continuing effort of a previous lost foam technology project. In previous stages of the project, there were significant measurable accomplishments, including:

- A single-station air gauge that has significantly improved the measurement of casting sections
- A technique that qualitatively and precisely measures coating properties that affect casting quality
- An instrument which allows accurate assessment of plant compactor vibration and reduces casting scrap

In the latest stage of the project, research is focused on extending the technology to be used with bronze and steel castings and continuing improvements to pattern consistency and coating optimization.

PARTNERS:	University of Alabama-Birmingham
OIT COST:	\$477,000
INDUSTRY COST-SHARE:	\$649,000
ENERGY SAVINGS:	4.6 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	0.45 million tons waste/yr in 2010
COST SAVINGS:	\$18.8 million/yr in 2010
EMPLOYMENT:	150 jobs (new base) in 2010
CONTACT:	Harvey Wong (202-586-9235)

INTELLIGENT CONTROL OF THE CUPOLA FURNACE

Cupola furnaces are used throughout the metal casting industry to melt ferrous metals prior to casting. Furnace operators must rely heavily on their experience and expert judgment to control the furnace. Operating a cupola furnace is based on rules of thumb rather than hard scientific facts, and it is difficult to optimize in terms of efficiency, productivity, and product quality. In addition, the industry is faced with the retirement of many of its experienced workers, leaving less skilled employees to do the job.

The AFS developed a comprehensive mathematical model of the cupola furnace for process control and optimization. This model is being used by Idaho State University in the current OIT research project, Intelligent Control of the Cupola Furnace. The research at Idaho State University focuses on developing for the cupola process a controller that uses intelligent and conventional control methods. The controller is being developed and tested on an experimental-sized cupola.

PARTNERS:	Idaho State University, Idaho National Engineering Laboratory, American Foundrymen's Society, National Technology Transfer Center
OIT COST:	\$425,000
INDUSTRY COST-SHARE:	\$895,000
ENERGY SAVINGS:	338 billion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	36 thousand tons waste/yr in 2010
COST SAVINGS:	\$17 million/yr in 2010
EMPLOYMENT:	180 jobs (new base) in 2010
CONTACT:	Gobind Jagtiani (202-586-1826)

SELECTED OIT METAL CASTING INDUSTRY R&D PROJECTS

DIMENSIONAL CONTROL AND FATIGUE LIFE PREDICTION

The Pennsylvania State University is involved with a project to characterize the dimensional capabilities of steel castings and to identify the important factors that control casting dimensional variability in steel foundries. Over 40,000 casting features have been measured on the production of steel castings in foundries throughout the United States.

The project has made several achievements, including the following:

- The dimensional repeatability of steel foundries are on average 40% better than are indicated in current U.S. and international standards
- Data analysis has clearly shown that many factors — including casting weight, feature length, feature type, and molding process control — influence the dimensional variability of casting features
- Measurement system analysis techniques have been applied and developed to permit accurate determination of casting dimensional variability. Industry guidelines in the form of a research monograph have been published

PARTNERS:	Pennsylvania State University, University of Missouri-Rolla, Wells Manufacturing
OIT COST:	\$686,000
INDUSTRY COST-SHARE:	\$823,000
ENERGY SAVINGS:	30 billion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	12 thousand tons waste/yr in 2010
COST SAVINGS:	\$12.6 million/yr in 2010
EMPLOYMENT:	20 jobs (new base) in 2010
CONTACT:	Gobind Jagtiani (202-586-1826)

- Improved pattern shrinkage allowance guidelines have been developed. This will permit the industry to better predict final casting dimensions. Study of corresponding casting lead times for new part production has shown that up to 50% of the lead time could be eliminated with accurate shrinkage allowance predictions.

EFFECT OF COMPOSITION AND PROCESSING ON THE THERMAL FATIGUE AND TOUGHNESS OF HIGH-PERFORMANCE DIE STEELS

Die casting is a process where molten metal is injected under pressure into a mold chamber which is formed by metal dies. A die caster usually casts aluminum, zinc, and some steel alloys. Case Western Reserve University is tasked with identifying ways to extend the lifetime of the metal dies by 20%. The 20% improvement in lifetime would result in a significant annual savings to the die casters, since the die or casting mold contributes to about 10% of the cost of diecast parts.

Tasks of this project include:

- Evaluating new die steel compositions that have been developed for demanding applications and comparing them to premium-grade H-13 die steel compositions
- Assessing, during heat treatment, the effects of fast, medium, and slow cooling rates on the thermal fatigue resistance and toughness of the die steel
- Determining the effect of electro-discharge machining on the thermal fatigue resistance and impact properties of the steel
- Selecting demanding components and conducting in-plant testing by using the new steel and comparing the performance of the new steel with identical components made of premium-grade H-13 steel

PARTNERS:	Case Western Reserve University, North American Die Casting Association, Nippon Koshuho Steel, Alloy Tool Steels, Latrobe Steel, American Specialty Metals and Associates, FPM
OIT COST:	\$244,000
INDUSTRY COST-SHARE:	\$161,000
ENERGY SAVINGS:	30 billion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	2,300 tons waste/yr in 2010
COST SAVINGS:	\$161 thousand/yr in 2010
EMPLOYMENT:	20 jobs (new base) in 2010
CONTACT:	Sara Dillich (202-586-7925)

One of the significant accomplishments of this project is that Case Western Reserve has been able to identify that KDA-1 (a kind of steel alloy) is superior to H-13 steel used in foundries today.

THE GLASS INDUSTRY

Economics and Competitiveness

Glass, a compound of many elements, and its products are as abundant and durable as the sands of the earth from which it is made. The industry that manufactures glass and glass products is an important component of the U.S. economy, employing in skilled jobs more than 150,000 people whose wages average about \$14/hour. The industry produces over 75,000 different products and, in 1994, shipped more than 21 million tons of product valued at nearly \$24 billion. The industry includes both major corporations and small family businesses that are spread across the nation, with an especially strong presence in California, Illinois, New York, West Virginia, Pennsylvania, and Ohio.

The glass industry is a mature, capital and energy intensive industry, challenged by low profit margins (which are typical for commodities production) and facing intermaterial as well as international competition. These conditions have reduced its reinvestment in R&D activities. In 1994, the industry's R&D expenditures as a percentage of sales were 1.75%, compared to the all-industry average of about 3%. While many new technologies have helped the glass industry become more competitive in the last two decades, most of these innovations have involved glass fabrication or finishing operations.

The glass industry is very sensitive to operating costs. Of the total operating costs of the U.S. glass industry, about 55% is for materials, 30% for labor, and 15% for energy. High-capacity utilization generally brings about lower unit energy consumption and improved productivity. The glass industry is also a capital intensive one, and in 1994 its capital expenditures amounted to \$1.1 billion — about 4.6% of sales.

Table 3-5. Glass Industry Profile

Value of Shipments	\$23.9 billion
Total Employment	152,000 jobs
Capital Expenditures	\$1.11 billion
Net Trade Balance	(\$440 million)
Energy Consumption	0.3 quadrillion Btu
Pollution Control Costs	\$285 million
Average Hourly Earnings	\$13.96

Though the raw materials (principally sand, limestone, and soda ash) and upstream melting and refining processes of the glass industry are quite similar, its downstream shaping and value-adding processes and products vary considerably. This contributes to an industry structure possessing four distinctive segments: (1) flat glass used largely for windows and windshields; (2) glass containers such as bottles and jars; (3) fiberglass for insulation and structural applications; and (4) pressed and blown specialty glass such as optical fibers, flat panel displays, and metallic glasses.

Business conditions in the flat glass and fiberglass industry segments are heavily influenced by the level of activity in the auto and construction industries that are their major customers. Conditions in the glass container segment, on the other hand, tend to be responsive to changes in consumer packaging and product preferences. Foreign competition is particularly strong for the flat and pressed and blown industry segments, while foreign trade in the container and fiberglass segments is less pronounced because of high transportation costs.

Figure 3-14. Glass Shipments by Industry Segment, 1994

Figure 3-15. Glass Industry Share of GDP

Source: OIT estimates from Department of Commerce data

THE GLASS INDUSTRY

Energy

The glass industry consumes about 300 trillion Btu/year (including electric power generation heat losses). Total energy expenditures exceed \$1.3 billion annually for the industry, with natural gas accounting for about 80% of end-use energy consumption and electricity accounting for about 16%. In 1994, the industry's energy cost as a percentage of sales was 5.6%.

On average, it takes around 14 million Btu to make a ton of glass, but depending on the type of glass product, it can vary from about 8 to 20 million Btu per ton of glass. The melting and refining step is the largest energy consumer; it typically accounts for 50% to 68% of total energy use in glassmaking. Forming typically accounts for 12% to 33% of energy use, while postforming accounts for 11% to 18%.

In flat glass, average energy consumption has declined from 23 million Btu/ton in 1976 to the current level of less than 13 million Btu/ton, with typical plant capacity of over 500 tons/day. In the container glass segment, the major use for natural gas is in melting (about 4.5 to 6 mmBtu/ton), with some consumption in annealing and finishing (for a total of 7 to 8 mmBtu/ton). In fiberglass, consumption of natural gas for melting has declined from about 28 mmBtu/ton in 1978 to the current level of about 6 to 8 mmBtu range. Unlike the container and flat glass sectors, a large amount of energy is used in the fabrication step, where fiberizing can consume an additional 6 to 10 million Btu/ton, with typical plant capacity of 75 to 150 tons/day. A large fraction of the pressed and blown sector consists of small, owner-managed manufacturers where energy consumption for melting is 12 to 16 mmBtu/ton shipped, with typical plant capacity of 75 tons/day. This segment of the industry generally depends on several energy intensive postforming operations, including annealing, tempering, and/or decorating.

Figure 3-16. Trends in Glass Industry Energy Expenditures

Source: Bureau of the Census

Figure 3-17. U.S. Glass Cullet Purchases by Glass Container Manufacturers

Source: Glass Packaging Institute

Environment

Air emissions are the major concern of the glass industry; the energy intensive melters emit NO_x and other emissions. The Clean Air Act Amendments of 1990 will require significant expenditures for equipment, monitoring, and permitting. Pollution abatement expenditures included \$71 million in capital costs and \$214 million in operating costs in 1994. Overall, pollution abatement costs as a percentage of sales were 1.2% in 1994.

Glass is highly recyclable; it can be remelted to create an un-degraded, high-quality product. Glass recycling exceeds that of plastics, but is less than that of most common metals, suggesting room for further improvement. An important factor limiting the recycling of glass is the relatively low cost of raw materials from which glass is made. This depresses the price of scrap glass and deters widespread collection efforts. The lack of an efficient scrap glass collection infrastructure, especially outside major urban areas, further limits glass recycling. In the future, however, glass container recycling is expected to increase significantly due to Government-mandated recycling laws, promotional activities of the glass companies that see a cost advantage in using more cullet, and the growth of voluntary recycling centers and collection systems.

Figure 3-18. U.S. Glass Container Recycling Rate

Source: Glass Packaging Institute

GLASS INDUSTRY VISION OF THE FUTURE

Industry Vision

"Glass: A Clear Vision for a Bright Future" is an industry-defined view of what it would like to look like in the year 2020. It identifies technology areas that are critical for the industry's future, including production efficiency, energy efficiency and conservation, environmental protection, recycling, and innovative uses.

The glass industry vision paves the way for joint industry-government technology partnerships. The glass industry believes a team approach to solving problems will provide easier access to technology, simplify participation in joint undertakings, and enhance communication and coordination. The industry is committed to public-private partnerships and believes the potential benefits will far outweigh the initial investment.

In theory, about 2.2 million Btu of energy are required to melt a ton of glass. In reality, considerably more energy is required because of inefficiencies and losses. To meet future challenges, the glass industry as a whole must enlarge the application of its technology and expand its usefulness to society through improvements in energy efficiency and other innovations. To remain vigorous and competitive, the glass industry has established the following goals:

- Operate with production costs at least 20% below 1995 levels
- Recycle 100% of all glass products
- Reduce process energy use from present levels by 50% toward theoretical energy use limits
- Reduce air and water emissions by a minimum of 20% through environmentally sound practices
- Recover, recycle, and minimize 100% of available post-consumer glass
- Achieve six sigma quality through automation, process control, optimized glass composition and strength, and computer simulation
- Create innovative products that broaden the marketplace
- Increase supplier and customer partnerships in raw materials, equipment, and energy improvements

Industry-Government Partnership

Anchor Glass Containers, Carr Lowrey Glass Company, Certainteed Corporation, Corning, Ford Motor Company, Glass Packaging Institute, Society of Glass Science and Practices, Techneglas, and Vetrotex-Certainteed signed a compact with the Secretary of Energy on April 29, 1996. The compact will enable collaboration in such areas as waste reduction, energy efficiency, and quality control — areas that dovetail with the overall public interest in clean air and water, less waste, and a healthy economy.

Technology Roadmap

The glass industry is developing a technology roadmap to help it achieve the goals articulated in its vision document. The roadmap is addressing all four of the principal industry segments: flat, container, fiberglass, and specialty. An industry-led subcommittee structure has been formed to focus on the principal technology challenges identified in the vision. Each subcommittee is led by an industry chairperson and includes representatives from all major segments of the industry. These subcommittees will be preparing an initial draft of the roadmap during the early months of 1997.

Figure 3-19. Glass Industry Employment by Industry Segment, 1994

Source: 1994 Annual Survey of Manufactures, Bureau of Census

GLASS INDUSTRY VISION OF THE FUTURE

DOE Glass Industry-Related R&D, FY 96

Relationship	Funding (million \$)	Number of Projects
Direct	1.4	6
Indirect	83.0	202
Total	84.4	208

Source: IPLocator database

Implementation of the Vision

Implementation of the glass industry vision will be a joint effort involving both the glass industry subcommittees and OIT's Glass Industry Team. Details of the implementation process are still being worked out, though the following activities will likely be included:

- Revise industry strategic vision to adjust for any major shifts in industry conditions
- Update research priorities identified in the roadmap
- Review OIT's current portfolio of glass industry projects
 - Receive, review, and recommend funding of research proposals
 - Identify and allocate resources
 - Reconcile planned activities and milestones with completed work

Glass Industry Technology Areas Targeted for Improvement

To achieve the goals, the glass industry agreed that technology improvements must be directed toward the following areas:

Production Efficiency

- Contact and noncontact glass temperature sensors; refractory temperature sensors and refractory thickness sensors; sensors that detect and assess the physical properties of glass, such as viscosity, during manufacturing; and sensors and controls that integrate and consolidate glass fabrication
- Glass coatings that maximize strength
- Alternate glass compositions that minimize or eliminate use of potentially hazardous materials
- Handling equipment that eliminates glass surface damage
- Improved gas and electric furnaces
- Computer models that simulate melting and refining processes, furnace performance, bottle forming, and tin bath characterizations to improve flatness

Energy Efficiency

- Optimizing electric boost to reduce total energy consumption
- Improving furnace design and operation to maximize combustion efficiency
- Recovering and reusing waste heat from oxy-fired furnaces
- Producing oxygen more efficiently for oxy-fuel firing

Recycling

- Separation of recycled glass by color
- Advancements in preparation of cullet (waste glass)
- Removal of nonglass contaminants that can damage equipment from the recycling waste stream

Environmental Protection

- Development of combustion processes that reduce air emissions
- Expanded use of 100% oxygen combustion
- Development of alternate materials or furnace designs that reduce or eliminate particulates
- New manufacturing processes that generate less solid waste
- Reuse of wastewater and solid waste, or use of solid waste as a raw material for other industries
- Development of refractories that do not generate hazardous materials
- Elimination of halide emissions associated with some types of specialty glass production

Innovative Uses

- Design of smart windows that react to natural lighting conditions and temperatures
- Lighter weight, impact-resistant containers and flat glass
- Fiberglass that compacts and rebounds easily
- New optical fiber designs and components capable of transmitting greater amounts of information

SELECTED OIT GLASS INDUSTRY R&D PROJECTS

GLASS FURNACE SIDE PORT OXYGEN ENRICHMENT

Regenerative glass furnaces used in continuous melting operations in the container and flat glass industries require extremely high combustion air temperatures (2000° to 2400°F) that yield NO_x emissions of up to 15 pounds/ton of glass produced. New low-cost, low-NO_x technologies for retrofitting natural-gas-fired regenerative glass furnaces are needed to help glass manufacturers comply with increasingly stricter emission regulations without losing their competitive edge.

The Institute of Gas Technology (IGT) has developed a process known as oxygen-enriched air staging (OEAS). OEAS technology uses a unique method of combustion air staging to control NO_x formation (reducing it up to 70%) by reducing the oxygen available in the flame's high-temperature zone and improving flame temperature uniformity. The cost of OEAS technology is expected to be less than one-fifth that of alternative NO_x abatement technologies. This project would enable the use of OEAS technology with sideport glass furnaces.

PARTNERS:	Institute of Gas Technology, Owens-Brockway Glass Container, Air Products and Chemicals, Combustion Tec
OIT COST:	\$615,000
INDUSTRY COST-SHARE:	\$1,450,000
ENERGY SAVINGS:	5.6 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	0.4 million ton waste/yr in 2010
COST SAVINGS:	\$37 million/yr in 2010
EMPLOYMENT:	300 jobs (new base) in 2010
CONTACT:	Ramesh Jain (202-586-2381)

DEMONSTRATION OF INTEGRATED BATCH AND CULLET PREHEAT SYSTEM FOR GLASS FURNACES

Recycled crushed glass, or cullet, accounts for up to 30% of the charge of raw material fed to the glassmaking furnace. Every 10% increase in cullet usage yields an approximate 3% reduction in energy requirements. Cullet preheating is used to further reduce energy consumption. However, as cullet use increases, the benefit from batch preheating — a technique used to reduce energy requirements and emissions of NO_x and particulates — diminishes, since cullet cannot be heated in most batch preheaters.

This project is developing a technology that utilizes waste heat to preheat both raw materials and cullet. The new preheater system will use furnace exhaust heat while recycling any condensable and particulate material in the exhaust stream. This technology increases furnace life through reduced temperature operation or, alternatively, increases production (throughput) at the same operating temperatures and furnace lifetime.

PARTNERS:	Corning, Tecogen, New York Gas, New York State Energy Research and Development Authority, Praxair
OIT COST:	\$1,383,000
INDUSTRY COST-SHARE:	\$1,682,000
ENERGY SAVINGS:	6.7 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	0.38 million ton waste/yr in 2010
COST SAVINGS:	\$13.1 million/yr in 2010
EMPLOYMENT:	180 jobs (new base) in 2010
CONTACT:	Merrill Smith (202-586-3646)

SELECTED OIT GLASS INDUSTRY R&D PROJECTS

HIGH LUMINOSITY LOW-NO_x OXY-GAS BURNER

Many furnaces used in the glass industry operate at very high temperatures, are energy inefficient, and emit high levels of NO_x and other pollutants. These problems can be alleviated by switching to oxy-fuel or oxygen-enriched air-fuel combustion. However, neither of these two processes provides the higher flame luminosity needed to achieve the level of radiant heat transfer to the charge material that will provide even higher efficiency and lower emissions by reaching glass tank bottoms and corners with radiant heat.

To further improve the performance of natural-gas-fired furnaces used in the glass, primary metals, and other energy intensive industries, OIT is collaborating with the Institute of Gas Technology to develop an innovative high-luminosity, low-NO_x burner for use in oxygen-enriched combustion systems. The burner is used to combine high-temperature natural gas preheating with soot formation in a fuel-rich and controlled-mixing combustion stage, and subsequent soot burnout with oxygen within the flame. The result is an increase in energy efficiency of more than 20%, increased furnace throughput, and decreased emissions of NO_x and other air pollutants. The burner can be retrofit to existing furnaces, including those that use oxy-fuel or oxygen-enriched air combustion.

PARTNERS:	Institute of Gas Technology, Combustion Tec, Owens-Corning Fiberglas
OIT COST:	\$229,000
INDUSTRY COST-SHARE:	\$336,000
CONTACT:	Ramesh Jain (202-586-2381)

SYNTHESIS AND DESIGN OF INTERMETALLIC MATERIALS

The wear and loss of glass refractories and components due to corrosion is a significant problem for glass manufacturers. Newly developed advanced materials, specifically molybdenum disilicide (MoSi₂) and its composites, have the potential for many applications in the glass industry because of their high-temperature properties and resistance to corrosion by molten glass. One potential application is the coating of furnace refractory bricks to slow down the degradation of the refractory from corrosion. Current refractory coatings also typically contain chrome, which causes a number of performance, energy-efficiency, and waste disposal problems for glass manufacturers.

This project is developing MoSi₂-based coatings and structural components for use in glassmaking furnaces. This material has elevated temperature strength, creep resistance, low-temperature fracture toughness, and high-temperature oxidation resistance, making it an ideal candidate for furnace applications. Advanced coatings and structural components fabricated from MoSi₂-based materials will also increase furnace energy efficiency and refractory life. Their use can also reduce operating & maintenance costs and the high landfilling costs associated with refractory bricks containing chrome, a hazardous material.

PARTNERS:	Los Alamos National Laboratory, Schuller International, Advanced Refractory Technologies, Air Products and Chemicals, Radian, Electro-Plasma, Exotherm
OIT COST:	\$1,550,000
INDUSTRY COST-SHARE:	\$1,000,000
CONTACT:	Charles Sorrell (202-586-1514)

SELECTED OIT GLASS INDUSTRY R&D PROJECTS

CONTACT TEMPERATURE SENSOR

Maintaining the correct processing temperature in a glass-melting furnace is critical to product quality and has a marked effect on energy usage. Sensors provide glass manufacturers with the necessary information to control the temperature of the molten glass in the furnace. However, the corrosive nature of molten glass (1) causes severe degradation of these sensors, (2) prevents them from delivering reliable and accurate temperature data over long periods of time, and (3) leads to energy and production inefficiencies and quality problems.

This project is developing a temperature sensor able to withstand the thermal shock and corrosive atmosphere of molten glass. Its enhanced abilities will improve the quality of glass products and reduce energy consumption and emissions by optimizing the melting temperatures needed to produce glass. At the same time, maintaining this temperature should improve both furnace productivity and product quality.

PARTNERS:	AccuTru International, INEL, Corning, Libbey Owens Ford, Owens Corning, Anchor Glass Container
OIT COST:	\$250,000
INDUSTRY COST-SHARE:	\$500,000
ENERGY SAVINGS:	26.2 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	3.1 million tons waste/yr in 2010
COST SAVINGS:	\$74.6 million/yr in 2010
EMPLOYMENT:	830 jobs (new base) in 2010
CONTACT:	Rolf Butters (202-586-0984)

DEVELOPMENT, EXPERIMENTAL VALIDATION, AND APPLICATION OF ADVANCED COMBUSTION SPACE MODELS

Though the amount of energy required to manufacture a ton of finished glass has decreased by a factor of three over the past two decades, the inability to control the heat flux distribution on the glass melt surface is considered a major obstacle to further reductions in glassmaking energy intensity. It also has a negative effect on both the life of the glassmaking furnace and the environmental impacts of the glass-melting process.

This project is developing three-dimensional combustion space models for glass-melting furnaces and validating their accuracy by using actual furnace data. The validated model can then be used to optimize the operation of current furnaces and to predict the performance of new ones based on their conceptual designs. The effect on energy and emissions performance of advanced heat transfer and pollution abatement techniques can also be modeled. The model could potentially reduce the energy intensity of glassmaking while providing a cost-effective method for manufacturers to prototype new process modifications and technologies.

PARTNERS:	Brigham Young University, Ford Motor Company
OIT COST:	\$258,000
INDUSTRY COST-SHARE:	\$636,000
CONTACT:	Ramesh Jain (202-586-2381)

THE CHEMICAL INDUSTRY

Economics and Competitiveness

Many view the chemical industry as the “keystone” manufacturing industry. This is because the preponderance of its products are inputs to other manufacturing industries as well as agriculture and mining. Of the 70,000 products produced by the chemical industry, the majority are feedstocks that improve the productivity and quality of goods manufactured by other industries (see Figure 3-20).

For example, the steel industry relies on oxygen to fire its furnaces. Fertilizers make American farms among the most productive in the world. Paints and plating compounds protect and extend the life of bridges, cars, and ships. Other chemical products include common consumer items like the detergents and medicine Americans depend on every day. Because of its basic, keystone role as a supplier to so many manufacturing and other industries, the performance and competitiveness of the chemical industry are both dependent on and contribute to the performance and competitiveness of the rest of the industrial economy.

The U.S. chemical industry is an exceptionally large, complex and diverse industry as well. In 1994 total shipments of the 9000 firms in the industry were valued at \$333 billion, and U.S. chemical companies accounted for about 24% of the world's total chemical output.

Clearly, due to its great size and diversity, the U.S. chemical industry has a major impact across the country and around the world. Firms in the industry — whose primary business involves the development, manufacture, and marketing of chemicals — are classified by the Federal Government's Standard Industrial Classification (SIC) system into the 2800 series, which covers industrial chemicals, pharmaceuticals, and other chemical products.

Table 3-6. Chemical Industry Profile

Value of Shipments	\$333 billion
Total Employment	824,000 jobs
Capital Expenditures	\$15.5 billion
Net Trade Balance	\$15.8 billion
Energy Consumption	5.5 quadrillion Btu
Pollution Control Costs	\$7.14 billion
Average Hourly Earnings	\$16.20

A major factor in the long-term success of the industry and a feature that largely distinguishes it from other basic industries has been its traditionally large R&D funding and its strong propensity to innovate. It was one of the first industries to support company-owned research labs, and nearly 100,000 scientists, engineers, and technicians are employed in chemical-related R&D. In 1994, the industry invested an estimated \$18 billion in R&D, up 165% from \$6.8 billion in 1983. About one out of every eight U.S. patents is awarded to a chemical industry employee.

The chemical industry's proficiency in innovative technologies and products has contributed much to its huge success in the global market. The chemical industry is the largest exporting industry in the U.S. economy — with 1994 exports valued at \$49.0 billion. Its trade balance (exports minus imports) in 1994 was \$15.8 billion. Because of the large value of chemical exports, the industry plays an especially critical role in the nation's overall trade picture. It is essential that the industry retain its traditionally strong, competitive stance at the risk of severely aggravating our country's chronic and disturbing trade deficit.

Figure 3-20. Chemical Industry Trade

Source: Bureau of the Census

Figure 3-21. Chemical Industry Share of GDP

Source: Department of Commerce

THE CHEMICAL INDUSTRY

Energy

The chemical industry is the second largest energy-consuming industry. In 1994, it consumed about 5.5 quads of energy. About 53% of chemical industry energy use is for fuel and power and the remainder is used for feedstocks. Most energy needs for heat and power in the chemical industry are met by natural gas and electricity. Natural gas is used to produce a number of important chemicals, including ammonia, hydrogen, methanol, and carbon black. Liquefied petroleum gas and refinery gas are used primarily in the production of petrochemicals like ethylene, propylene, and vinyl chloride.

Some segments of the chemical industry are very energy intensive; for example, energy costs in the industrial gas segment of the industry account for 40%-50% of total operating costs. Overall, four segments of the chemical industry — inorganic chemicals, organic chemicals, plastics, and fertilizers — consumed about 85% of all fuel and electricity used in the chemical industry in 1994 (see Figure 3-22).

The overall efficiency of energy use in the chemical industry has improved by over 40% since 1974. This is because of improved technology and energy management as well as a general shift toward the production of less energy intensive products. Simultaneously, the proportion of energy used for feedstocks in the chemical industry has grown from 39% in 1970 to 48% presently. Much of this increase can be attributed to growth of the plastics business.

Table 3-7. Chemical Industry as a Source of Key Industrial Pollutants, 1994 (in million tons)

Pollutant	U.S. Total	Industrial Processes	Industrial Combustion	Chemical Processes
SO _x	21.12	1.99	3.03	0.46
NO _x	23.62	0.80	3.21	0.29
VOCs	23.17	2.70	0.14	1.58
CO	98.02	3.61	0.67	2.05
Particulates	2.69	0.62	0.24	0.06
Lead	0.0050	0.0020	0.000015	0.000093

Source: National Air Quality and Emissions Trends Report, 1994; EPA

Figure 3-22. Sources and Uses of Energy in the Chemical Industry, 1994 (estimated, in quads Btu)

Environment

The chemical industry generates about 2 billion tons of waste per year. While some of the waste chemicals are emitted into the air as gas and particulate pollution, the majority of the waste generated by the chemical industry is wastewater from the industry's manufacturing processes. Indeed, in 1989, 91% of the industry's waste left chemical plants as wastewater. Air pollutants from industrial production of chemicals include sulfur dioxide, nitrogen oxide, carbon monoxide, suspended particulates, VOCs, and lead.

In addition, concern about the role greenhouse gases play in the changing character of our climate has focused largely on carbon dioxide, which makes up about 55% of these emissions. Of the 1.4 billion metric tons of carbon emissions released in the United States in 1994, the chemical industry was the source of 3% and remaining industrial sources were responsible for almost 18%.

In an attempt to protect the environment and the health of all Americans, Federal and State governments have imposed a number of laws and compliance and reporting requirements. As a consequence, pollution abatement and control costs have tempered the industry's profitability. The cost of regulations lowers profits, restrains new capital investment, and holds down the productivity gains for their industry. The chemical industry spends more than the other U.S. industries for pollution abatement and control — \$7.1 billion in 1994. For the years 1989-93, total pollution abatement control costs for chemicals companies of \$14.3 billion slightly exceeded the whole industry's \$14.2 billion total after-tax profits.

CHEMICAL INDUSTRY VISION OF THE FUTURE

The chemical industry, through its representative organizations — such as the Chemical Manufacturers Association (CMA), the American Chemical Society (ACS), the American Institute of Chemical Engineers (AIChE), the Council for Chemical Research (CCR), and the Synthetic Organic Chemical Manufacturers Association (SOCMA) — and OIT are working together to develop clean, energy-efficient manufacturing technologies that will ensure continued global leadership of U.S. chemical companies and products. This partnering process will focus technology development on the highest priority needs of industry and align Federal investment in RD&D with the needs of technology users in the private sector.

Industry Vision

In 1994, technical and business leaders in the chemical industry began to study the factors affecting the competitiveness of their industry and its rapidly changing business environment. This work, also of interest to the White House Office of Science and Technology Policy, focused on identifying the common technology challenges that will face the industry over the next 25 years.

In the spring of 1996, the industry's sponsoring organizations approved "The Technology Vision 2020: Report of the U.S. Chemical Industry." The report, "a call to action, innovation, and change," sees the U.S. chemical industry in 2020 as

- Leading the world industry
- Being responsible for breakthroughs in R&D that enhance the quality of life

- Creating innovative process and product technologies
- Setting a world standard for excellence in manufacturing operations and efficient use of energy and raw materials
- Being a responsible neighbor
- Creating a seamless partnership or "virtual" laboratory for originating and developing innovative technologies
- Promoting sustainable development

The report concludes that the growth and competitive advantage of the chemical industry depends on individual and collaborative efforts of industry, government, and academia to improve the nation's R&D enterprise.

The "Vision 2020" report identifies four targeted areas:

- New chemical science and engineering technology
- Supply-chain management
- Information systems
- Manufacturing operations

Focused efforts in these areas can assist the industry in meeting the challenges it faces.

Industry-Government Partnership

In the winter of 1996, representatives from the chemical industry's sponsoring organizations signed a voluntary cooperative agreement (or compact) with the Department of Energy. The agreement sets forth the framework for a collaborative effort of identifying appropriate joint RD&D activities involving the Federal Government and the chemical industry.

Figure 3-23. Chemical Industry Markets, 1994 (in billion \$)

CHEMICAL INDUSTRY VISION OF THE FUTURE

Technology Roadmap

Industry leaders will be joined by OIT's Chemical Industry Team to begin work on a system of technology roadmaps. This will help define the process for implementing the R&D areas identified in the chemical industry's vision. These roadmaps will serve as a framework that guides industry, academia, and government R&D efforts in developing energy-efficient and pollution-preventing technologies for the chemical industry into the 21st century.

To further encourage and provide coordination for the chemical industry's R&D agenda, OIT works closely with the Laboratory Coordinating Council (see page 14) to identify activities of interest to the industry at DOE's National Labs. In turn, the Council identifies for the chemical industry the core R&D competencies and corresponding points-of-contact for specific research activities at the Labs.

DOE Chemical Industry-Related R&D, FY 96

Relationship	Funding (million \$)	Number of Projects
Direct	31.7	88
Indirect	66.3	289
Total	98.0	377

Source: IPLocator database

THE U.S. CHEMICAL INDUSTRY'S PROFICIENCY IN INNOVATIVE TECHNOLOGIES AND PRODUCTS HAS CONTRIBUTED MUCH TO ITS SUCCESS IN THE GLOBAL MARKET.

SELECTED OIT CHEMICAL INDUSTRY R&D PROJECTS

CENTER FOR WASTE REDUCTION TECHNOLOGIES

The Center for Waste Reduction Technologies (CWRT) is a division of the American Institute of Chemical Engineers. CWRT is an industry-driven organization that sponsors and develops innovative waste reduction technologies and methodologies. CWRT sponsors targeted research, technology transfer, and enhanced education in collaboration with industry, government, and academia. In late 1994, CWRT signed a cooperative agreement with the U.S. Department of Energy, covering all aspects of the Center's operation, with special emphasis on collaborative research.

DOE and CWRT are supporting cost-shared, precompetitive R&D projects that offer substantial opportunities to reduce waste generation and improve environmental quality. The emphasis is on research that advances long-term, generic technology solutions on which commercial technologies can be subsequently based. In addition to supporting R&D, DOE cooperates with CWRT in technology and information dissemination, collaborative technical workshops, and education programs for industry.

PARTNERS:	Center for Waste Reduction Technologies
OIT COST:	\$975,000
INDUSTRY COST-SHARE:	\$975,000
CONTACT:	Charles Russomanno (202-586-7543)

PHENOLICS FROM WOOD WASTE

The wood composites that are often used in place of solid wood in furniture and other products are manufactured with adhesives made from phenol formaldehyde (PF) resins. Production of these resins requires more than 1 billion pounds of relatively expensive petroleum-based phenol each year. Low-cost phenolics derived from waste biomass could replace a large portion of the petroleum feedstock requirements because of the relatively low phenol purity requirements of PF resins.

DOE and industry have been cost-sharing the development of low-cost, high-performance adhesives specifically tailored for composite wood products. Scientists have developed technology to convert waste biomass, or lignin, into a mixture of phenolic compounds that can be formulated directly into PF resins or combined with petroleum-derived phenol to produce PF resins that meet industrial standards. In either case, the result is a lower cost adhesive with significant benefits to the environment, and reduced use of nonrenewable resources.

PARTNERS:	National Renewable Energy Laboratory, AlliedSignal, Aristech Chemical, Plastics Engineering, Georgia Pacific Resins, Energy Conversions, Ensyn
OIT COST:	\$6,723,000
INDUSTRY COST-SHARE:	\$10,250,000
ENERGY SAVINGS:	8.12 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	8.24 million tons waste/yr in 2010
COST SAVINGS:	\$3.52 million/yr in 2010
EMPLOYMENT:	420 jobs (new base) in 2010
CONTACT:	Charles Russomanno (202-586-7543)

SELECTED OIT CHEMICAL INDUSTRY R&D PROJECTS

RECOVERY OF CHLOROSILANE INTERMEDIATES BY A NOVEL WASTE CONVERSION PROCESS

The U.S. silicon industry is facing competitive pressures from foreign producers. New technologies that would enable basic silicone producers to recycle wastes associated with the production of silicon would enhance the competitive position of domestic producers. One such technology is being developed to convert chlorosilane monomers, dimers, and heavier silicon-containing compounds into useful chemical intermediates.

OIT is working with industry to convert silicon by-products of limited value into methylchlorosilane intermediates that can be recycled through the silicon production process as feedstock. Energy is saved by displacing the raw materials used to produce silicon and by increasing chloride recycle efficiency. Another benefit is a reduction in the landfilling of direct process residue (DPR), one of the by-products recovered in the new process. The recovery of DPR conserves the considerable embodied energy of the silicon contained within it.

PARTNERS:	Dow Corning
OIT COST:	\$129,000
ENERGY SAVINGS:	521 billion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	148 thousand tons waste/yr in 2010
COST SAVINGS:	\$1.49 million/yr in 2010
CONTACT:	Brian Volintine (202-586-1739)

INORGANIC POLYMER MEMBRANE

Polymeric membranes have been used for many years for commercial separations such as upgrading natural gas and producing industrial gases. Polymeric materials offer several advantages for these applications, including relatively low materials cost; the ease of forming a thin, defect-free film for flat sheets or hollow fibers; and the ability to fabricate robust membrane modules. The use of polymeric membranes has been restricted primarily by their low resistance to organic solvents and their limited thermal stability.

OIT has been developing a new class of polymers for membrane separations that overcome the limitations of traditional polymeric materials. Membranes made from these new polymers, known as polyphosphazenes, can be designed to have high solvent resistance and can operate in high temperatures and/or harsh environments. Polyphosphazene membranes have the ability to separate chlorinated hydrocarbons and other organics from water, and acid gases from other gases. Separation energy requirements can be reduced by approximately one-third using the new membrane-based process.

PARTNERS:	Idaho National Engineering Laboratory, Union Carbide, Media & Process Technology
OIT COST:	\$2,486,000
INDUSTRY COST-SHARE:	\$1,204,000
ENERGY SAVINGS:	38.9 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	2.36 million tons waste/yr in 2010
COST SAVINGS:	\$187 million/yr in 2010
EMPLOYMENT:	1220 jobs (new base) in 2010
CONTACT:	Ehr-Ping Huang Fu (202-586-1493)

SELECTED OIT CHEMICAL INDUSTRY R&D PROJECTS

LEVULINIC ACID

Each year, the U.S. pulp and paper industry produces millions of tons of paper sludge containing fines and other wastewater treatment materials that are also rich in carbohydrates. Since the heat value of this material is too low to justify burning it for cogeneration purposes, it is typically landfilled. However, recent R&D has suggested that a high-value chemical product known as levulinic acid could be manufactured from this sludge.

Although levulinic acid has numerous potential uses, its high cost inhibits large-scale use. OIT is working with a National Lab, private industry, and the New York State Energy Resources Development Agency to develop expanded uses of levulinic acid. If this work is successful, landfill needs could be reduced and a nonpetroleum-based feedstock would be available for the manufacture of certain plastics, fuel additives, and pesticides.

PARTNERS:	National Renewable Energy Laboratory, Biofine, New York State Energy Research & Development Authority
OIT COST:	\$195,000
INDUSTRY COST-SHARE:	\$300,000
CONTACT:	Gloria Kulesa (202-586-8091)

COMPARISON OF ADVANCED DISTILLATION CONTROL METHODS

Distillation, a separation technology widely used in the chemical and petroleum industries, is responsible for about 3% of total U.S. energy consumption. Distillation is often carried out conservatively to ensure that product purity specifications are met. Unfortunately, this extra processing consumes up to 50% more energy than is actually required to achieve the desired product specifications.

Although many options exist for applying advanced distillation controls, the lack of comparative data makes it difficult for industry to make informed choices. OIT is funding the development of information that will enable the chemical and refining industries to make economical choices on different control options. Detailed dynamic simulations of distillation processes are yielding data on the relative performance of both conventional and advanced controls as a function of column control difficulty. It has been estimated that an overall 15% reduction of distillation energy consumption could be achieved if better column controls were applied.

PARTNERS:	Texas Tech University, Texaco, Diamond Shamrock, Aspentech, Phillips, Setpoint, Amoco, Ethyl, Johnson Yokagawa, Hypotech, Exxon
OIT COST:	\$326,000
CONTACT:	Charles Russomanno (202-586-7543)

SELECTED OIT CHEMICAL INDUSTRY R&D PROJECTS

AUTOMOBILE MATERIALS RECYCLING

The U.S. automotive industry has a strong interest in providing for increased recycling of the materials from current as well as future vehicles. Through its Partnership for a New Generation of Vehicles (PNGV), the industry has set a goal of increasing the amount of recyclable automotive materials from today's industry average of 75% (primarily metal components) to at least 80%. OIT is participating in the PNGV efforts by developing advanced separation technologies to recover high-quality materials from obsolete cars, and methods to recycle scrap tires back into new rubber products.

Most of the estimated 10 million motor vehicles that are scrapped each year are recycled through auto shredder operations, producing millions of tons of steel scrap. For each ton of steel recovered, about 500 pounds of nonmetallic materials — known as auto shredder residue (ASR) — are generated. With OIT support, technology for recovering polyurethane foam, iron-oxide-rich fines, and certain thermoplastics from ASR has been developed as an alternative to landfilling this material. The clean foam can be used to produce carpet padding and other products; the iron oxides can be upgraded for use in the cement industry.

Recycling scrap tires presents another opportunity for recovering valuable automotive materials. Each year 70 million worn-out tires — equivalent to 2 billion pounds of tire rubber and 200 million pounds of steel and fiber — are added to the over 800 million waste tires that have not been put to beneficial use. OIT is developing technology to economically convert these tires into higher value products, conserving

PARTNERS:	Argonne National Laboratory, American Automobile Consortium, Composite Particles
OIT COST:	\$13,000,000
INDUSTRY COST-SHARE:	\$6,500,000
ENERGY SAVINGS:	120 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	9.7 million tons waste/yr in 2010
COST SAVINGS:	\$503 million/yr in 2010
EMPLOYMENT:	1880 new jobs (new base) in 2010
CONTACT:	Simon Friedrich (202-586-6759)

energy and raw materials while reducing the landfilling of scrap tires. The technology converts finely ground tire rubber to polymer composites for use in tires, shoe soles, vehicle parts, and other products. OIT is also investigating a process for recycling the rubber scrap generated during the manufacture of rubber products. The overall goal is to use at least 10% recycled rubber in new tires.

ADVANCED ELECTRODIALYSIS FOR SEPARATIONS AND POLLUTION PREVENTION IN PROCESS INDUSTRIES

Many of the waste streams generated during industrial process operations have become economic as well as environmental burdens. Some of these waste streams in the chemical, pulp and paper, and pharmaceutical industries contain salts contaminated with organics which can be recovered through the novel application of advanced electrodialysis technologies. To explore this potential, OIT is sponsoring a project at Argonne National Laboratory, with assistance from NTEC ED Sep, to develop, demonstrate, and commercialize electrodialysis applications for these and other industries.

In another effort in this project, Argonne is developing a novel process, direct esterification, to produce lactate ester at a production cost where it can economically replace large volumes of chlorinated and other toxic industrial solvents that are used in a wide variety of industries. As an additional benefit, with this novel process, lactate ester can replace lactic acid as a chemical intermediate in certain applications, leading to the more efficient production of biodegradable plastics as well as several large-volume chemicals. Argonne National Laboratory is working with NTEC Illinois to commercialize this novel process.

PARTNERS:	Argonne National Laboratory, NTEC ED Sep, BioPlasTek, Plastigone, University of Florida
OIT COST:	\$1,405,000
INDUSTRY COST-SHARE:	\$7,150,000
ENERGY SAVINGS:	27 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	5.9 million tons waste/yr in 2010
COST SAVINGS:	\$277 million/yr in 2010
EMPLOYMENT:	4740 jobs (new base) in 2010
CONTACT:	Merrill Smith (202-586-3646)

SELECTED OIT CHEMICAL INDUSTRY R&D PROJECTS

FLEXIBLE CHEMICAL PROCESSING OF POST-CONSUMER POLYMERIC MATERIALS INTO CHEMICALS

Only a small percentage of plastic waste is recycled. The present constraints on plastic recycling are high costs, constraints on waste contamination, and lack of adequate separation prior to recycling. Pyrolysis — a process whereby plastic wastes are heated in the absence of oxygen — has shown promise in the recovery of basic chemicals and fuels from waste plastics. Research sponsored by OIT has led to the development of a new process based on the pyrolysis of certain waste streams to retrieve monomers and high-value chemicals that are sufficiently pure to use in making new plastics.

The new pyrolysis process has been demonstrated for waste carpet recycling. Caprolactam, the valuable monomer of Nylon 6 used in about half of all carpet fibers, can be isolated with high yields without separating the nylon from the backing material. The cost of the recycled caprolactam is expected to be much less than that of virgin caprolactam. The process also has potential applications in recovering valuable chemicals from polyurethane foam (such as found in scrapped automobiles), mixed plastic bottles, and mixed residential plastics.

PARTNERS:	National Renewable Energy Laboratory, AlliedSignal
OIT COST:	\$3,027,000
INDUSTRY COST-SHARE:	\$2,916,000
CONTACT:	Charles Russomanno (202-586-7543)

BIOPROCESSING TECHNOLOGIES

Today, the majority of chemical-manufacturing processes rely on catalysts to increase the rate of production (reaction). In living cells, catalysis is carried out by naturally occurring enzymes. These enzymes are thought to have significant potential for applications in the chemical- and petroleum refining industries. However, the enzymes perform best in water-based systems at room temperature and atmospheric pressure — not typical conditions for chemical processing. If enzymes can be found, engineered, or adapted to operate in the extreme environments that typify chemical processes, the chemist's tool kit would be greatly expanded.

Biocatalysts are used currently in the pharmaceutical industry and the production of a small number of industrial chemicals. However, biocatalysts become fragile under harsh manufacturing conditions and are slow to react. Chemists have little experience in designing biocatalysts that can perform a desired function. As a result, OIT's Biological Technologies Program promotes the use and facilitates the introduction of bioprocesses by developing enzymatic microbial catalysts. Such catalysts can be readily employed in chemical process operations and in improving other key aspects of bioprocessing. As a result, OIT supports two major biological R&D activities — biocatalyst design and bioprocessing systems.

OIT-sponsored research focuses on designing innovative new computer-aided tools for enzyme modeling, using metabolic and protein engineering to design new biocatalysts, searching for new and useful biocatalysts, and developing an understanding of the catalytic process for chemical transformations. In addition, OIT is working to advance the state-of-the-art in bioprocessing and to facilitate the use of biotechnology in producing commodity chemicals and wood pulp.

PARTNERS:	Oak Ridge National Laboratory, Massachusetts Institute of Technology, California Institute of Technology, National Renewable Energy Laboratory, University of Pittsburgh, Dow Chemical, AlliedSignal, Lawrence Berkeley Laboratory
OIT COST:	\$3,799,000
INDUSTRY COST-SHARE:	\$2,552,000
ENERGY SAVINGS:	10 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	6.7 million tons/yr in 2010
COST SAVINGS:	\$38 million/yr in 2010
EMPLOYMENT:	570 jobs (new base) in 2010
CONTACT:	David Boron (202-586-0080)

THE PETROLEUM REFINING INDUSTRY

Economics and Competitiveness

The petroleum refining industry — with shipments of about \$128 billion in 1994 — supplies refined products that meet the fuel and lubricant needs of more than 190 million cars, vehicles, and all aircraft. Refined petroleum products are also used in industry, power generation, and home heating. In addition, refineries supply raw materials used in the manufacture of many chemicals, from ammonia to plastics.

Refineries typically use large quantities of heat to distill crude oil, crack the resultant intermediate products into smaller molecules, and then purify and blend the various fuels to produce a number of useful products. Gasoline is the principal refinery product, accounting for over half of industry sales.

The U.S. refining industry is the largest in the world, currently accounting for about 21% of total world capacity. It is also the world's most technologically sophisticated refining industry — a result of the need to simultaneously (1) process huge volumes of heavy, high-impurity crudes; (2) improve the yield of light-weight, high-octane, unleaded transportation fuels; and (3) comply with a number of stringent environmental statutes.

U.S. refining capacity is about 15 million barrels per day (bpd), with a utilization rate that has been exceeding 90%. However, no grassroots refineries have been built in the United States for more than a decade nor are any under construction. Indeed, the number of operating refineries has decreased from about 285 in the late 1960s to about 175 currently.

Table 3-8. Petroleum Refining Industry Profile

Value of Shipments	\$128 billion
Total Employment	71,700 jobs
Capital Expenditures	\$5.22 billion
Net Trade Balance	(\$5.2 billion)
Energy Consumption	5.9 quadrillion Btu
Pollution Control Costs	\$5.40 billion
Average Hourly Earnings	\$21.64

The decline in operating refineries has been due primarily to the closure of smaller refineries unable to process heavier oils or make the investments needed to comply with environmental regulations. Unlike industries such as steel, aluminum, and paper, where increased recycling is spurring the growth of minimills, in the petroleum refining industry increasing competition, environmental regulation, technological complexity, and capital requirements are forcing the closure of smaller plants.

Overall, imports of foreign crude oil and refined petroleum products supply almost half the U.S. market. Finished petroleum products — largely gasoline, distillate, and residual fuel oil — accounted for 21% of all U.S. oil-related imports in 1994. Exports constitute about 5% of U.S. refinery output. A number of major oil exporting nations are increasing their refining capacity. This will create more competition for U.S. refiners facing generally mature markets.

Figure 3-24. Value of Product Shipments by Type, 1994

Sources: EIA, 1994 Annual Survey of Manufactures, Bureau of the Census

Figure 3-25. Petroleum Refining Industry Share of GDP

Source: OIT Estimates from Department of Commerce data

THE PETROLEUM REFINING INDUSTRY

Energy

The petroleum refining industry is the single largest energy-using industry, consuming a total 5.9 quads in 1994. About 50% of the energy consumed by petroleum refining is used to manufacture feedstocks such as asphalt, lubricants, and waxes. The rest — amounting to almost 3 quads in 1994 — is used for heat and power.

Over half the energy used in petroleum refining is by-product refinery waste gas; petroleum coke, another refinery by-product, is also an important fuel source. Together, these two in-house by-product fuels supplied 60% of refinery heat and power needs in 1994.

Petroleum refining involves both chemical and mechanical energy changes. Although some conversion processes are exothermic, most are endothermic and require large amounts of heat. Such processes include distillation, cracking, hydrotreating, reforming, and alkylation. A large amount of mechanical energy is also needed for pumping, transportation, compression of gases, and the like.

Improved energy efficiency has been a major priority of the petroleum refining industry since the sharp increase in energy prices in the 1970s. Total energy consumption per barrel of crude processed has been estimated at 584,000 Btu in 1990, down from a reported 673,000 Btu in 1973. Of course, the actual efficiency gain is considerably higher than indicated by this 15% improvement because the industry has become considerably more complex since 1973 and in effect produces much higher quality products.

Figure 3-26. Sources and Uses of Energy in the Petroleum Refining Industry, 1994 (estimated)

Total = 5917 Trillion Btu

Source: EIA

Environment

The refining process yields a spectrum of solid, liquid, and air emissions, many of which are subject to regulatory control. Roughly three-fourths of solid waste from refining is aqueous wastes, with the remainder consisting of contaminated soils, oily sludges, spent catalysts, and chemicals and inorganic wastes. Major pollutants include air emissions (sulfur oxides, nitrogen oxides, and carbon monoxide), heavy metals, VOCs, toxic air emissions, spent solvents and catalysts, and naturally occurring radioactive materials. The biggest environmental challenge faced by petroleum refiners may be controlling airborne emissions of key pollutants.

Environmental constraints, in the form of government regulations and public opposition to expansion, are an ever-increasing burden on U.S. refiners. Recent public policy and regulatory developments have increased refining costs by requiring significant capital investments with uncertain returns to meet new product quality mandates. This is reflected in the very high expenditures for pollution abatement and control — \$5.4 billion in 1994. This represents more than 15% of the value added for this industry (compared to 1.5% for all manufacturing).

Moreover, implementation of the Clean Air Act Amendments of 1990 is expected to create additional costs and technical challenges for refiners. In some instances, it may be more economic for certain refineries to close partially or entirely rather than upgrade facilities to meet the new regulations. Hence, there are strong incentives to develop and adopt innovative approaches and cost-effective technologies to ensure that the industry will remain competitive. Unless cost-effective solutions are found, the competitiveness of U.S. refiners could be severely impaired and the general viability of the industry threatened.

Figure 3-27. Petroleum Refining Industry Cost of Pollution Abatement

Source: Bureau of the Census

PETROLEUM REFINING INDUSTRY OF THE FUTURE

Between 1997 and 2020, improvements in the efficiency of oil and gas use are likely to be more than offset by increases in demand that are caused by growth in the standard of living and population. The EIA has projected that consumption of petroleum products in the United States will thus increase from 34 quads in 1992 to about 42 quads by the year 2010. Refineries in the United States will have a geographic advantage in capturing a large share of this market, but will also be subject to increasingly stringent governmental regulations. In addition, refineries will have to find ways to economically accommodate the trend toward lower quality crude oil.

Industry Vision

To address the numerous environmental, energy, and economic challenges of the coming decades, the petroleum refining industry will need to develop and implement a variety of cleaner and more cost-effective process technologies. However, individual refineries are finding it increasingly difficult to devote the necessary funds to R&D. Much of the needed research (precompetitive) could be conducted in collaboration with Government, National Labs, and universities. To provide strategic direction for technology research, industry leaders have been working together to envision the future regulatory environment, feedstock supplies, product demand, global competition, and technology needs.

In 1994, industry groups met to discuss these issues at a workshop sponsored by the National Petroleum Refiners Association (NPRA) and Argonne National Laboratory in cooperation with DOE. The following themes — reflecting some of the challenges facing the industry in the future — emerged from this workshop:

- The future industry structure will reflect strong competitive pressures, because of the industry's maturity, rising cost structure, capital intensity, standards of profitability, and bias toward large and complex facilities.
- In the future, petroleum refining will evolve from current industry fundamentals. That is, petroleum will remain the primary feedstock; most existing processes will survive; foreign links will remain strong; and there will be continued pressure to develop better capabilities, process controls, and information systems.
- Over the next decade, the industry will be shaped by environmentally driven regulations. As a consequence, a positive working relationship

between regulators and industry will be needed to support competitiveness. This includes working with EPA to develop scientifically sound solutions and establish a commonsense basis for regulatory initiatives. The industry will also collaborate with automobile manufacturers to optimize fuel and engine systems for gasoline and diesel.

- The industry's key needs are for environmental and advanced basic technologies as well as an improved knowledge of the linkages between fuels, vehicles, and air quality.

A more recent report, "Research, Development and Demonstration Needs of the Oil and Gas Industry," published by the National Petroleum Council (NPC) in 1995, further characterizes the future of the refining industry by 2020. The NPC report addresses the need for flexibility, compliance with environmental regulations, new chemistries, and structural materials. Furthermore, industry processing will need to become far more flexible to easily accommodate changing product demand as well as changes in the quality levels of crude oil. This flexibility will be achieved through the industry-wide application of "agile" manufacturing techniques. In addition to increasing industry flexibility, these sophisticated techniques will increase facility utilization rates and require a smaller and more skilled workforce. In addition, new types of catalysts will permit major improvements in existing refining processes and pave the way for completely new chemical processes that could revolutionize refining.

Figure 3-28. Trends in Number of U.S. Refineries and Refinery Capacity

Source: EIA

PETROLEUM REFINING INDUSTRY OF THE FUTURE

Finally, the NPC report envisions operational improvements to existing processes and the implementation of new processes as a result of new structural materials. Advanced materials with greater strength and resistance to corrosion can support the development of more efficient processing operations. These materials, along with the use of nondestructive, online testing techniques, will help to extend plant life and the service life of plant equipment. In addition, such testing techniques are likely to reduce downtime, incident rates, and maintenance costs.

DOE Petroleum Refining Industry-Related R&D, FY 96

Relationship	Funding (million \$)	Number of Projects
Direct	12.2	36
Indirect	66.0	211
Total	78.2	247

Source: IPLocator database

Industry-Government Partnership

In fulfilling research needs, the refining industry is willing to work in partnership with other oil and gas companies, Government, National Labs, universities, and other consortia. The industry's willingness to enter into such partnerships has increased with the emergence of the new paradigm in oil and gas R&D: user-driven technology development. The industry has taken the first steps in defining its vision and will proceed to further develop specific research pathways and synergistic alliances.

THE STRUCTURE AND CONFIGURATION OF U.S. REFINERIES HAVE CHANGED DURING THE PAST 25 YEARS.

SELECTED OIT PETROLEUM REFINING INDUSTRY R&D PROJECTS

HYBRID MEMBRANE SEPARATION FOR PROPYLENE RECOVERY

Petroleum refineries typically use a number of physical and chemical processes to convert crude oil into gasoline and hundreds of other products. One process — catalytic cracking — is used to increase the yield of lighter and more valuable products such as gasoline. The waste gases from the catalytic cracking process contain propylene, a potentially valuable compound used to make plastics. To recover propylene, the components of the waste gas are separated using a two-tower distillation system. The distillation process is very energy intensive, with energy efficiencies seldom exceeding 10%. OIT has sponsored the development of a propylene recovery system that combines a membrane unit with a single distillation column.

The new hybrid membrane distillation system has shown substantial cost savings in both retrofitted operations and new facilities. Because the membrane unit is cheaper than a distillation column, the hybrid system is expected to have capital costs of as much as 25% less than the conventional distillation system; similar savings are expected in operating and maintenance costs.

PARTNERS:	BP Chemicals
OIT COST:	\$2,100,000
INDUSTRY COST-SHARE:	\$3,000,000
COST SAVINGS:	\$458 million/yr in 2010
EMPLOYMENT:	600 jobs (new base) in 2010
CONTACT:	Ehr-Ping Huang Fu (202-586-1493)

THE ORIGIN AND DISPOSITION OF TOXIC COMBUSTION BY-PRODUCTS IN PROCESS HEATERS

The boilers and process heaters used in petroleum refineries burn natural gas and a fuel known as refinery fuel gas. Beginning in the year 2000 these boilers and heaters, which emit hazardous air pollutants, will be regulated for these emissions by provisions in the Clean Air Act Amendments of 1990. According to this legislation, 189 pollutants, many of which are carcinogenic, were identified as hazardous.

New low-cost burner designs and combustion process modifications are needed that can minimize the formation of these hazardous emissions. To help the petroleum refining industry prepare for efficient compliance with the upcoming regulations, OIT is sponsoring research on air-toxic emissions from refinery boilers and process heaters using various burner technologies. Goals of this work include the establishment of the current state of such emissions, development of an understanding of their origin and eventual disposition, and development of an understanding of the mechanisms of their formation and destruction so that new operating conditions and burner technologies that produce fewer toxic emissions may be developed.

PARTNERS:	Sandia National Laboratories, Lawrence Livermore National Laboratory, Petroleum Environmental Research Forum
OIT COST:	\$2,944,000
INDUSTRY COST-SHARE:	\$3,006,000
ENERGY SAVINGS:	8 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	450 thousand tons waste/yr in 2010
COST SAVINGS:	\$12 million/yr in 2010
EMPLOYMENT:	50 jobs (new base) in 2010
CONTACT:	Gideon Varga (202-586-0082)

SELECTED OIT PETROLEUM REFINING INDUSTRY R&D PROJECTS

FOULING MECHANISMS

The overall energy efficiency of petroleum refineries is dependent on the efficiency of the heat exchangers used to recover thermal energy from high-temperature refining processes. Fouling buildup in the heat exchanger tubes impedes heat transfer, lowering thermal efficiency. U.S. refiners lose an estimated 0.2 quad of energy and more than \$2 billion each year because of heat exchanger fouling. A recent increase in the use of heavy oil and residuum in refineries is exacerbating the fouling problem.

To address this problem, OIT has undertaken a cooperative effort to develop new and improved methods to mitigate fouling in several key petroleum refining processes. Researchers are investigating the major causes of fouling, developing methodologies to predict threshold conditions for different feedstocks, and developing new techniques to improve the effectiveness of chemical additives that prevent fouling deposition. Data developed in the laboratory will be validated through field experiments.

PARTNERS:	Argonne National Laboratory, HTRI, Chevron, Shell, Nalco
OIT COST:	\$2,800,000
INDUSTRY COST-SHARE:	\$1,400,000
CONTACT:	Ehr-Ping Huang Fu (202-586-1493)

PRODUCTION OF ETHANOL FROM REFINERY WASTE GASES

Petroleum refineries discharge hydrogen, carbon monoxide, and carbon dioxide waste gases to the atmosphere. Converting these waste gases into useful chemicals would reduce pollution while decreasing the amount of these chemicals that would otherwise have to be produced from nonrenewable feedstocks. Scientists are currently examining the feasibility of producing the chemical ethanol from crude oil refinery waste streams. More than 1 billion gallons of ethanol are produced in the United States each year, much of which is blended with gasoline to reduce vehicle emissions. Currently ethanol is produced from fermented corn at a cost of about \$.90/gallon just for raw material (corn) costs; substantial tax credits are applied to keep the cost of blended fuel economical. However, sharp growth is expected in the demand for blended fuels as vehicle emission restrictions are tightened.

The production of ethanol from waste refinery gases will significantly reduce ethanol costs, allow expansion of the markets for blended fuels, reduce air pollution from both refineries and vehicles, and reduce fuel imports. The conversion process being investigated uses bacteria to convert the gases to ethanol, followed by purification steps similar to those used in the corn-based process. The process can also be applied to other processes that have waste carbon monoxide and hydrogen streams, such as the production of the chemicals methanol and ammonia, and those used in coke-making ovens in the steel industry.

PARTNERS:	Bioengineering Resources
OIT COST:	\$1,098,000
INDUSTRY COST-SHARE:	\$1,242,000
ENERGY SAVINGS:	16 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	11 million tons waste/yr in 2010
COST SAVINGS:	\$1.27 billion/yr in 2010
CONTACT:	Merrill Smith (202-586-3646)

SELECTED OIT PETROLEUM REFINING INDUSTRY R&D PROJECTS

ADVANCED FLUID CATALYTIC CRACKER

The manufacture of reformulated gasolines that reduce emissions as prescribed by the Clean Air Act Amendments of 1990 will have a profound impact on the operation of petroleum refineries. Particular attention is being given to the FCC unit; regulatory mandates can be achieved most effectively by altering the FCC unit to produce more oxygenates (which have low emissions when combusted) and olefins while reducing the yields of undesirable products such as heavy gasoline. The key to modifying the FCC process is to develop a more fundamental understanding of its physical and chemical behavior.

With OIT and industry sponsorship, researchers are developing advanced technology for the next generation of FCC units, technology that will be able to tailor product yields to more closely match the mandated gasoline formulas. Using computer models, the design of current FCC units will be modified to decrease the use of catalysts, increase the production of light gasoline fractions, reduce capital and operating costs, and reduce levels of aromatics and sulfur in the gasoline fraction.

PARTNERS:	Argonne National Laboratory
OIT COST:	\$890,000
INDUSTRY COST-SHARE:	\$500,000
CONTACT:	Ehr-Ping Huang Fu (202-586-1493)

STEAM CRACKING, HIGH-PRESSURE HEAT EXCHANGE SYSTEM

The energy efficiency and productivity of the metal alloy heat exchangers used in many petrochemical processes are limited by the performance of these alloys at high temperatures. Advanced ceramic materials can maintain strength at much higher temperatures than metal alloys. The use of ceramic components in heat exchangers could substantially improve the efficiency of thermal cracking of petroleum feedstocks and other refining processes. In addition to their high-temperature performance, ceramic materials are more corrosion resistant than metal alloys.

In a cooperative effort with industry, OIT is helping to develop ceramic components for application in the thermal furnaces used in the production of ethylene, propylene, butadiene, and other chemicals. Specifically, a ceramic coil retrofit is being developed that will allow the furnace to operate at higher temperatures, thereby increasing efficiency while improving product yield. The net result is more product made using less energy for the same amount of petroleum feedstock. The ceramic coil is also thought to inhibit coking, a problem that commonly occurs with conventional metallized coils and contributes to high maintenance costs.

PARTNERS:	Stone & Webster, Oak Ridge National Laboratory
OIT COST:	\$2,716,000
INDUSTRY COST-SHARE:	\$862,000
ENERGY SAVINGS:	6.5 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	155 thousand tons waste/yr in 2010
COST SAVINGS:	\$22 million/yr in 2010
EMPLOYMENT:	90 jobs (new base) in 2010
CONTACT:	Gideon Varga (202-586-0082)

THE FOREST PRODUCTS INDUSTRY

Economics and Competitiveness

The U.S. forest products industry is divided into two major segments: lumber and wood products, and pulp and paper products. Collectively, in 1994 the industry produced wood and paper products valued at about \$247 billion and employed 1.34 million workers.

The lumber and wood products segment of the forest products industry grows, harvests, and processes wood and wood fiber, and processes solid wood products. Domestic lumber production has grown sharply over the past decade from about 36 billion board feet in 1985 to 46 billion board feet in 1994. About half of all lumber is used in the construction of residential housing. In 1994, the lumber and wood products segment of the industry employed about 719,000 workers and shipped products valued at about \$104 billion.

The pulp and paper segment of the forest products industry manufactures pulp, paper, and paperboard products from virgin and recycled fiber. It is subdivided into two principal sectors. The energy intensive mill sector processes raw materials, such as wood and recycled paper, into sheets of paper and paperboard; the converting sector further processes the sheets of paper into other finished products such as envelopes and boxes.

Our economy's appetite for information contributes to the fact that U.S. per capita paper consumption is the highest in the world. The pulp and paper industry output grew from about 61 million tons in 1980 to about 85 million tons of paper and paperboard products in 1993, nearly equally divided between paper and paperboard products. In 1994, the paper industry shipped products valued at \$144 billion and employed 621,000 workers whose average hourly wages of \$14.33 exceeded the average worker's hourly pay by about 29%.

Table 3-9. Forest Products Industry Profile

Value of Shipments	\$247 billion
Total Employment	1,340,000 jobs
Capital Expenditures	\$9.86 billion
Net Trade Balance	(\$5.4 billion)
Energy Consumption	3.3 quadrillion Btu
Pollution Control Costs	\$3.11 billion
Average Hourly Earnings	\$11.77

The pulp and paper segment of the industry has invested heavily in new equipment in the past decade, with capital expenditures averaging about 10% of sales, about twice as high as those of the manufacturing sector as a whole. On average the paper industry has invested more than \$120,000 per worker — more than any other manufacturing industry. Notably, environmental improvements have replaced additions to capacity as the driving force behind capital-spending plans. Otherwise, equipment is replaced only when necessary due to the large capital costs of new equipment in this high-productivity, scale-economy industry.

Our country's vast domestic forest resources underpin our major role in the world forest products industry. In 1994, exports of wood and paper products amounted to \$18.3 billion, and the principal destinations were Japan, the European Community, and Mexico. In that same year, imports of forest products totaled \$22.3 billion for a net industry trade deficit of about \$4 billion. Canada and the Scandinavian countries traditionally have been our strongest competitors, but competition from developing countries with large forest resources, such as Chile, is increasing.

Figure 3-29. Trends in Forest Products Industry Shipments

Sources: Census of Manufactures and Annual Survey of Manufactures (various years)

Figure 3-30. Forest Products Industry Share of GDP

Source: Department of Commerce

THE FOREST PRODUCTS INDUSTRY

Energy

In 1994, the forest products industry consumed about 3.3 quads of energy, making it the third largest energy-using industry in the United States, behind only petroleum refining and chemicals. Of the total used by the industry, the lumber and wood products segment used about 520 trillion Btu and the pulp and paper segment used 2.8 quad Btu.

It is perhaps not widely recognized but the forest products industry makes extensive use of renewable resources to meet its energy needs. Indeed, almost two-thirds of all renewable fuels consumed by the U.S. industrial sector is accounted for by the industry's use of black liquor, bark, and wood for fuel.

Also, the industry generates over 40% of the total on-site electricity generated by U.S. manufacturing industries, mostly by using cogeneration. The paper industry meets more than 50% of its energy needs with self-generated and residue fuels like bark, hogged fuel, and black liquor, a by-product of the pulping process. Even with its large use of renewable sources, the industry spent about \$8.0 billion on purchased energy in 1994, or nearly 3.2% of the value of its shipments.

On average, about 31 million Btu are currently used to produce a ton of paper. The three most energy intensive steps account for 83% of the energy consumed by the pulp and paper industry: pulping accounts for 26%, chemical recovery requires 19%, and papermaking consumes 38%.

Environment

Land available to grow harvestable wood is diminishing, and pressures are building to remove more public lands from commercial forestry. This will tend to increase wood and paper prices and force the industry into using lower quality woods that typically require more intensive use of energy for processing.

Water pollution control is a major environmental issue facing the industry. Waste streams from chlorine bleaching can contain toxic materials, including dioxins. Major sources of pollutants include digester and evaporator condensates, bleach plant filtrates, and paper machine white water.

This industry also produces air emissions; estimated annual emissions include 300,000 tons of NO_x , 600,000 tons of SO_x , and 160,000 tons of particulates.

Figure 3-31. Pulp and Paper Industry Energy Sources, 1993

Source: American Forest & Paper Association

In 1994, the industry spent more than \$2.3 billion to operate pollution control equipment. It also invested \$810 million in pollution abatement that same year, about 7.8% of its capital expenditures. Moreover, the industry is facing unprecedented increases in operating and capital costs and energy use in order to comply with the more demanding environmental regulations that are expected over the next decade.

The industry recycles huge amounts of wastewater and currently recovers an estimated 40% of all paper used. Its objective is to increase this rate to 50% by the year 2000. As noted previously, the industry also uses large quantities of its waste wood and pulping liquor as boiler fuel.

Figure 3-32. Growth in Recycling as Percent of Total Paper Production

Source: American Forest and Paper Association

FOREST PRODUCTS INDUSTRY VISION OF THE FUTURE

The forest products industry and OIT are working together to promote forest and paper industry growth, energy efficiency, and international competitiveness while preserving the environment. A partnership involving the Federal Government, industry, universities, National Laboratories and suppliers has been established based on a common vision of the future.

Industry Vision

In May 1994, Secretary of Energy Hazel O'Leary and Denise Swink, Deputy Assistant Secretary for Industrial Technologies, spoke at the Institute of Paper and Science and Technology board meeting. They challenged the industry to develop an industry-wide vision to guide its future technology development activities.

In November 1994, the forest products industry responded by publishing "Agenda 2020: A Technology Vision and Research Agenda for America's Forest, Wood and Paper Industry." Agenda 2020 observes that never before has the industry with such unanimity taken a look at its future, the need for technology development, and ways to leverage its own capabilities with partnerships involving other institutions, suppliers, and government. The vision identifies the following goals for the research partnership:

- To advance the global competitiveness of the forest products industry by building technological leadership in spite of subsidies in major competitor nations in recent decades

- To continue improving the sustained management of the forest resource, recognizing its multiple uses and its essential position as an available, stable, low-cost raw material base to the industry
- To be capable of meeting demanding environmental requirements without the predicted increases in capital expenditures, operating costs, and energy consumption
- To continue the significant progress in building energy self-sufficiency and to take full advantage of available biomass by-products as a fuel source
- To increase further the economic viability and use of recycled wood and paper materials

The research partnership will demonstrate, evaluate, and accelerate new technologies and scientific insights that address crosscutting national needs. These needs must be met in order to continue taking advantage of the unique benefits of wood-based products, such as their low embodied energy and renewability as a raw material. Agenda 2020 lays out a framework for addressing industry needs in six critical areas:

- Energy performance
- Environmental performance
- Capital effectiveness
- Recycling
- Sensors and control
- Sustainable forestry

Industry-Government Partnership

In November, 1994, in Richmond, Virginia, Secretary O'Leary and Robert Williams, CEO of James River Corporation, signed a compact establishing a research partnership involving the forest products industry and DOE. While industries had entered into partnerships with the Government before, this partnership added a new feature: The entire forest products industry was unified behind one strategic technology plan — Agenda 2020.

The plan identifies the major manufacturing and environmental challenges confronting the industry and its customers. On behalf of the industry, DOE facilitates a broad cross-section of Federal agencies in helping to develop and implement a coordinated strategic technology roadmap that can address the industry's principal challenges. The partnership attempts to do this while leveraging a shrinking budget — in other words, it seeks to do more with less.

LOGS ARRIVE AT A MILL, TO BE PROCESSED INTO PULP.

FOREST PRODUCTS INDUSTRY VISION OF THE FUTURE

Technology Roadmap

In close concert with the American Forest and Paper Association (AF&PA), OIT's Forest Products Team facilitates the implementation of the research agenda. For each of the six technology areas identified in Agenda 2020, task groups have been assembled that include representatives from industry, universities, and Government. Each of the task groups has developed a detailed research agenda — called research pathways — that is consistent with the overarching goals of Agenda 2020.

DOE Forest Products Industry-Related R&D, FY 96

Relationship	Funding (million \$)	Number of Projects
Direct	11.3	23
Indirect	34.9	132
Total	46.2	155

Source: IFLocator database

Implementation of the Vision

The task groups then examine precompetitive research needs and identify strategies, goals, and pathways with emphasis on high-impact areas. The task groups recommend appropriate resources and target institutions to address the needs. The task groups reviewed 179 projects and recommended 21 to DOE for funding in 1996. OIT funded 20 of the 21 projects at a level of \$4.3 million. Over 500 projects have been submitted for review and funding consideration in 1997.

Del Raymond, the Weyerhaeuser executive who co-chairs the committee implementing Agenda 2020, characterizes the new government-industry partnership as "an evolution with few dramatic movements. It's a good progressive evolution that's happening on a time schedule. There are so many people involved that the real challenge now is communication."

He has seen dramatic changes in Government's responsiveness to industry's needs already. "Professors have told me, absolutely yes, things that used to take 18 months, now are done in less than 3 months. The full process has not been completed yet, but if it continues on the same track, it will be fantastic," he said.

Even though the research to implement Agenda 2020 is just beginning, the process has already paid dividends for the forest products industry. In its negotiations with EPA concerning the Cluster Rule, the AF&PA used Agenda 2020's research agenda to demonstrate its commitment to solving its environmental problems. This, in turn, caused EPA to reconsider the most onerous provisions of the rule.

Figure 3-33. International Trends in Paper Use

SELECTED OIT FOREST PRODUCTS INDUSTRY R&D PROJECTS

BLACK LIQUOR GASIFICATION

Black liquor — the combination of dissolved wood waste and used pulping chemicals — is currently burned in recovery boilers to recover the chemicals for reuse and to use the embodied energy content of the wood waste to generate steam for use in the mill. Although quite efficient, the recovery boiler has limitations. Scientists are working on a black liquor gasification process that would increase the flexibility and safety of black liquor recovery while allowing even more energy to be recovered. In this new process, the liquid black liquor would be heated enough to convert it into a gas. The pulping chemicals are then separated out and recovered, leaving the remaining gas to perform double duty as a heat source to generate steam in a boiler and subsequently as a fuel to be burned in an electricity-generating gas turbine. This dual use of a single fuel is known as cogeneration.

The benefits of using gasification are numerous and include improved safety, decreased environmental impact, higher energy efficiency, and lower operating costs. The smelt formed at the bottom of a conventional recovery furnace poses a small but deadly risk in the form of smelt explosions, one of the most feared occurrences at a pulp mill. Smelt can't form in the gasifier, so the risk is eliminated. The gasifier process reduces emissions of particulates, SO₂, and NO_x. The energy efficiency of the gasification process is higher than that of the recovery boiler because there is no smelt (a major source of heat loss) and because of the high energy conversion efficiency of the cogeneration process. Additional environmental benefits of the technology could be achieved if it is proven viable with biomass feedstocks such as paper mill sludge.

PARTNERS:	Manufacturing & Technology Conversion International, ThermoChem, Stone & Webster, Weyerhaeuser, Stonechem
OIT COST:	\$11,591,000
INDUSTRY COST-SHARE:	\$4,792,000
ENERGY SAVINGS:	22 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	1.85 million tons waste/yr in 2010
COST SAVINGS:	\$54 million/yr in 2010
EMPLOYMENT:	750 jobs (new base) in 2010
CONTACT:	Valri Robinson (202-586-0937)

BIOMASS GASIFICATION

More than half of the pulp and paper industry's energy needs are met by renewable and by-product energy sources, including hogged wood, bark, and spent black liquor solids. These biomass fuels are typically used in cogeneration systems to generate process steam and electricity for use in the mill. Excess electricity is sold to local electric utility companies. The industry has expressed interest in adapting and integrating even more advanced biomass energy conversion technologies into pulp and paper mill operations.

One advanced technology being investigated with help from OIT is a biomass gasification combined-cycle system for generating process steam and electricity. The biomass fuel is gasified to produce a medium-Btu biogas that can be either fed to a combined-cycle unit to generate electricity or burned directly as a fuel. The gasification combined-cycle system has a higher efficiency and lower capital intensity than conventional energy conversion technologies. Locally grown biomass energy crops may be used in addition to pulp and paper mill biomass wastes to generate electricity for sale to local customers.

PARTNERS:	Weyerhaeuser, NREL
OIT COST:	\$377,000
INDUSTRY COST-SHARE:	\$372,000
CONTACT:	Valri Robinson (202-586-0937)

SELECTED OIT FOREST PRODUCTS INDUSTRY R&D PROJECTS

IMPULSE DRYING

During papermaking, the newly formed paper is transferred from the main body of the paper machine to the dryer section, where it passes over steam-heated drying cylinders. This drying process is the single largest energy use in the papermaking process. The moisture content of the paper entering the dryer section is less than 50%. A new technology known as impulse drying is being developed to reduce the moisture content of paperboard (the type of paper used in boxes) during pressing, the last step before drying. Impulse drying uses a very hot roll to squeeze the paper; the combination of steam (formed at the hot roll surface) and compression to expel water from the sheet, resulting in a moisture content of less than 40%. This greatly reduces the energy required in the drying section and allows the entire paper machine to run faster, thus increasing productivity.

On a national basis, adopting impulse drying on paperboard machines could result in energy savings of nearly 6 trillion Btu each year. This would reduce emissions of CO₂ by 1.1 million tons, NO_x by 2400 tons, VOCs by 80 tons, and particulates by 4000 tons annually. Impulse drying also enables paperboard manufacturers to use a much higher percentage of recycled fiber — as much as 80% — than they are able to use with conventional technology. Increased use of recycled fiber means that less new pulp is needed, with a corresponding decrease in the use of pulping chemicals and in pulping-related pollution. Finally, paperboard made with impulse drying is stronger than its conventional counterpart and can meet product specifications at a lower weight, thereby reducing pulp requirements even further. Because pulp requirements are directly proportional to a mill's demand for wood, using impulse drying will also reduce the number of trees cut.

PARTNERS:	Institute of Paper Science and Technology, Beloit Corporation
OIT COST:	\$5,259,000
INDUSTRY COST-SHARE:	\$504,000
ENERGY SAVINGS:	6 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	7.7 million tons waste/yr in 2010
COST SAVINGS:	\$996 million/yr in 2010
EMPLOYMENT:	5,990 jobs (new base) in 2010
CONTACT:	Valri Robinson (202-586-0937)

ULTRASONIC SENSOR

The development of online sensor technologies that can measure mechanical and strength properties of paper could greatly improve the productivity and energy and raw material efficiency of papermaking. With traditional offline testing methods, large amounts of substandard product can be produced before a problem is detected and corrected. This is especially critical for the heavier weight grades such as packaging paper and paperboard, where strength is extremely important.

The online ultrasonic velocity measurement technology being developed by OIT and industry will be able to determine the elastic stiffness of paper as it is being made, allowing quick corrections. Minimizing the amount of substandard production that must be repulped and remanufactured saves energy and raw materials. The paper product also has improved uniformity and performance, which allows the subsequent converting processes to be performed more efficiently. For some products, the specified strength may be able to be achieved with less pulp, allowing the use of a higher percentage of recycled fiber.

PARTNERS:	Institute of Paper Science & Technology
OIT COST:	\$2,908,000
INDUSTRY COST-SHARE:	\$2,730,000
ENERGY SAVINGS:	2 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	110 thousand tons waste/yr in 2010
COST SAVINGS:	\$9 million/yr in 2010
EMPLOYMENT:	100 jobs (new base) in 2010
CONTACT:	Tom Foust (202-586-0198)

SELECTED OIT FOREST PRODUCTS INDUSTRY R&D PROJECTS

RECOVERY OF CHEMICALS FROM PAPER MILLS USING ELECTROLYSIS

Although efforts to apply membrane-based technologies to the recovery of chemicals from black liquor have been tried before, membrane fouling problems have prevented these technologies from achieving success.

Under OIT sponsorship, a new membrane-based electrolytic system is being applied to the recovery of sodium from black liquor. The sodium, in the form of sodium hydroxide solution, can be reused in the pulping process, and the sodium-free black liquor can be burned more efficiently in the recovery boiler. The new electrolytic process is also applicable to the recovery of sodium and chlorine from the bleaching process waste stream. The recovered chemicals can be recycled into the bleaching process, saving energy and reducing the environmental impacts of bleaching.

PARTNERS:	Osmotek, Boise Cascade
OIT COST:	\$1,718,000
INDUSTRY COST-SHARE:	\$522,000
ENERGY SAVINGS:	1.2 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	64 thousand tons waste/yr in 2010
COST SAVINGS:	\$547 million/yr in 2010
EMPLOYMENT:	6090 jobs (new base) in 2010
CONTACT:	Valri Robinson (202-586-0937)

POLYOXOMETALATE BLEACHING

Traditionally, bleach plants have used fresh water for washing pulp between bleach stages. This practice requires large amounts of fresh water, substantial energy to heat the water, and the subsequent discharge of large volumes of effluents. A closed-cycle mill would produce virtually no effluent, saving chemical feedstock, energy, and water. Although some closed-cycle systems have been implemented, they have encountered many problems.

A new bleaching process being investigated by OIT could provide a cost-effective option for a closed-mill system. Polyoxometalates have been shown to be very effective agents for highly selective bleaching of softwood kraft pulps, acting similarly to the agents used by wood-rotting fungi to degrade lignin. Starting with a fully integrated bench-scale unit, the program is expected to culminate in the construction of a pilot-scale facility by industry. In addition to saving energy and reducing waste streams, the technology could enhance the competitive position of the U.S. pulp and paper industry in the global market by reducing the costs for producing bleached pulps.

PARTNERS:	U.S. Dept. of Agriculture Forest Products Laboratory, Emory University
OIT COST:	\$500,000
INDUSTRY COST-SHARE:	\$137,000
CONTACT:	Valri Robinson (202-586-0937)

CROSSCUTTING TECHNOLOGY PROGRAMS

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The Heat Engine of Choice in the Competitive Power Industry

During the past 15 years, the structure of the U.S. electric power industry has begun to change in important ways. Stimulated by the Public Utilities Regulatory Policies Act of 1978 (PURPA) and the Energy Policy Act of 1992 (EPACT), the traditionally stable U.S. electric power industry is giving way to a highly competitive one. Deregulation will lead to cheaper electricity as new opportunities for distributed generation and cogeneration arise.

Cogenerators and other nonutility power generators operated more than 5000 facilities in the United States by the end of 1992 and accounted for 55 gigawatts (GW), or 7%, of installed U.S. electric power capacity. More significantly, they accounted for more than half of all U.S. power capacity additions between 1988 and 1992. A classification of independent power production by industry at the end of 1994 is provided in Figure 4-1. EPACT started changes that are sweeping through the electric utility industry today.

Gas turbines, whether in simple or combined-cycle configurations, have been the heat engine of choice in the competitive power generation industry. Gas turbines range in size from 6 kilowatts (kW) to over 200 megawatts (MW). They operate on natural gas, distillate fuel oil, crude oil, residual fuel oil, or synthesis gas derived from coal or biomass. Turbine manufacturers have developed highly efficient, reliable, clean, and relatively inexpensive combustion turbines in various capacities for use in power generation facilities. Because of their relatively low first cost, high efficiency, short lead times, high reliability, and superior environmental performance, gas turbine-based systems play an important role in new generating capacity.

Figure 4-1. Independent Power Production, 1994

Total = 57 GW

Recent trends in industrial cogeneration illustrate the growing reliance on gas turbine systems. In 1985, just after PURPA began to have significant effect on the nonutility generation market, the majority (62%) of capacity in industrial cogeneration applications was based on conventional boiler, steam turbine systems. Most of the remaining capacity (30%) was based on gas turbine systems. By 1991, however, gas turbine systems accounted for over 47% of the generating capacity in industrial power generation, while conventional boiler, steam turbine configurations provided less than half (49%) of the industrial cogeneration capacity online in 1991.

Gas Turbine Systems Will Dominate New Generating Capacity

EIA forecasts that a total of 172 GW of new generating capacity will be required by 2010 to meet the expected growth in electric power demand. Moreover, a significant portion of existing generating capacity is expected to require replacement or undergo repowering during this time period. Such trends and developments portend a growing need for more efficient, cleaner advanced gas turbine and cogeneration systems.

The move toward a more competitive power generation market may further increase the role of the nonutility segment of the industry and enhance opportunities for cogeneration. Industrial users and nonutility power producers often choose gas turbine systems because they are easier to site and quicker to develop than similar-sized alternatives. In addition, emissions from natural gas-fired turbine systems are significantly lower than emissions from similarly-sized coal or oil power plants. Simple and combined-cycle gas turbine systems are expected to be employed in almost 60% of the 61 GW of new capacity planned by the nonutility power industry through 2000.

The efficiency, flexibility, reliability, and other benefits of simple or combined-cycle gas turbine systems are prompting utilities to employ such systems as well. Though designed primarily to meet peak and intermediate load requirements, these systems are also able to meet baseload requirements if necessary.

ADVANCED TURBINE SYSTEMS AND COGENERATION

Figure 4-2. Planned New Generating Capacity by Technology, 1990-2000

Source: Utility Data Institute

Continuing Advancements in Gas Turbine Technology Will Be Needed

Despite the advantages gas turbines offer, power producers must meet increasingly stringent emissions requirements, new capacity needs, and increasing competitive pressure to improve efficiency. Improved turbine systems are needed to ensure reliable and economic electricity supplies, to help meet national energy efficiency and environmental goals, and to maintain the world leadership position of U.S. turbine manufacturers. To achieve significant improvements, advanced turbines are needed that operate at higher firing temperatures while maintaining low emissions levels. However, manufacturers are reaching the limit of traditional technology approaches. Future advances in turbine technology will require significant turbine design changes, development and application of new materials, and use of innovative power cycles.

Advancements are also needed to ensure that U.S. gas turbine manufacturers remain competitive in the growing world market as the global market for power generation equipment becomes increasingly important to U.S. manufacturers. Annual exports for gas turbines, with a total value of \$2 billion annually, will grow to \$3.5 billion annually. While U.S. manufacturers have traditionally been strong in this overseas market (40% of all gas turbine sales between 1988 and 1994 were from U.S. manufacturers), foreign manufacturers are aggressively pursuing technology improvements to challenge this position. Continued technology advancements will be critical for U.S. manufacturers to remain competitive in this important global market.

Although many of the turbine advancements for the private sector resulted from technology developed through military R&D programs, direct Government funding for civilian turbine development has historically been minimal. However, the technical and economic risks involved in the next generation of advanced turbine systems will be much greater than in the past, and private industry is not expected to pursue these advances without risk-sharing in the form of a Government-industry cost-sharing program.

OIT's Advanced Turbine Systems and Cogeneration Program conducts extensive research, development, and demonstration to meet the technical and market challenges

associated with enhancing industrial cogeneration and moderate-sized independent power production opportunities. Current program thrusts include the development of high-efficiency, low-emission gas turbine systems; a high-performance steam system; and a ceramic retrofit gas turbine.

Cogeneration and Combined-Cycle Generation

Cogeneration is the production of both electrical (or mechanical) and thermal energy from the same primary energy source. Combined-cycle generation is similar to cogeneration except that the exhaust heat from a gas turbine is recovered and then fed back to a boiler and used by a steam turbine to provide a second electricity-generating cycle. The principal advantage of cogeneration systems is their ability to improve the efficiency of fuel use and reduce overall emissions. In a topping system, electricity is produced first and the remaining thermal energy may be used for industrial processes. In a bottoming system, thermal energy is first used for very high-temperature industrial processes such as steel or glass furnaces, and the exhaust gases then fuel boilers that drive turbines to produce electricity.

SELECTED OIT ADVANCED TURBINE SYSTEMS AND COGENERATION R&D PROJECTS

ADVANCED TURBINE SYSTEM

OIT is developing advanced turbine systems with DOE's Office of Fossil Energy (FE), the Electric Power Research Institute, the Gas Research Institute, the Environmental Protection Agency, and others in response to the Energy Policy Act of 1992, Section 2112 ("Heat Engines"). The goal for advanced turbine system efficiency is a 15% improvement over today's best gas turbine systems; reduced emissions of NO_x, CO₂, CO, and UHC; and a 10% reduction in the cost of generating electricity for both utility and nonutility power generators by 2002. FE is developing the utility gas turbines. Initial advanced turbine systems will be natural-gas fired; these gas turbines will be capable of burning coal, biomass, or other solid fuels. The OIT program is targeting the development of a new industrial-application turbine with a power-generating capacity of less than 20 MW.

The advanced turbine system will need to operate at higher firing temperatures and higher pressure ratios to achieve higher efficiency. Higher firing temperatures will require manufacturers to incorporate such features as ceramic components and better turbine blade cooling techniques. Operating at these temperatures alone will not meet the desired efficiency goals, however; manufacturers will need to make innovative cycle changes using compressor cooling, heat recovery, turbine reheat, and moisture injection technologies. The advanced turbine system will use advanced low-NO_x burners, thereby eliminating the need for costly emissions control equipment.

PARTNERS:	Solar Turbines, Allison, Howmet, AlliedSignal, DuPont Lanxide, ORNL, EPRI, Indianapolis Power & Light, GRI, U.S. Turbine, Fluor Daniel, Others
OIT COST:	\$15,289,000
INDUSTRY COST-SHARE:	\$10,000,000
ENERGY SAVINGS:	81.6 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	4.6 million tons waste/yr in 2010
COST SAVINGS:	\$293 million/yr in 2010
EMPLOYMENT:	2440 jobs (new base) in 2010
CONTACT:	Pat Hoffman (202-586-6074)

HIGH-PERFORMANCE STEAM SYSTEM

Steam turbine systems (a boiler to generate the steam and a turbine to convert it to electricity) are used as both stand-alone systems and with gas turbines in combined-cycle systems for industrial cogeneration. The efficiency of these systems has changed little since temperature and pressure limits were set in the 1950s. These limiting conditions are mostly a result of the corrosion and erosion problems that occur when conventional steam system components are operated at high temperatures. If these problems could be overcome, however, steam temperature and pressure could be raised, resulting in increased generating efficiency (and thus power output). To address these long-standing limitations, OIT is sponsoring the development of a high-performance steam system (HPSS) for industrial cogeneration applications.

The HPSS technology is based on using two advanced steam-cycle components. One is a high-temperature boiler whose tubes are made from Inconel 617, an exceptionally strong nickel alloy that is capable of withstanding high temperatures without wearing out. The second component is an efficient, high-speed steam turbine that incorporates state-of-the-art turbine blade materials technology borrowed from gas turbines. A system based on HPSS technology can handle steam with a pressure of 1500 pounds per square inch and a temperature of 1500°F, compared with current maximum conditions of about 900 pounds per square inch and 1000°F. This translates into an increase in conversion efficiency of more than 50% and an increase in electricity generation of more than 20% — both increases achieved using the

PARTNERS:	Solar Turbines, Innovative Steam Technologies, INCO, Precision Cast Parts, Fischer Valves
OIT COST:	\$1,893,000
INDUSTRY COST-SHARE:	\$300,000
ENERGY SAVINGS:	68.1 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	6.2 million tons waste/yr in 2010
COST SAVINGS:	\$132 million/yr in 2010
EMPLOYMENT:	880 jobs (new base) in 2010
CONTACT:	Pat Hoffman (202-586-6074)

same amount of steam. Compared to the typical industrial practice of operating with conditions as low as 600 pounds per square inch and 750°F, the HPSS will more than double both power output and turbine efficiency.

SELECTED OIT ADVANCED TURBINE SYSTEMS AND COGENERATION R&D PROJECTS

CERAMIC RETROFIT GAS TURBINE

The performance of current gas turbines is limited by the temperature and strength capabilities of the metallic structural materials in the engine hot section. Much progress has been made in the development of ceramic components for various high-temperature environments; now attention is focusing on integrating such components into stationary gas turbines such as those used by industrial cogenerators and electric utilities. Using ceramic components would allow higher turbine inlet temperatures without cooling, thus improving the thermal efficiency of gas turbines.

Because of their superior high-temperature strength and durability, OIT is currently sponsoring a cooperative program with industry to develop uncooled ceramic components such as nozzles, blades, rotors, and combustor liners for gas turbines. When combined with innovative turbine designs, these advantages translate into a significant improvement in thermal efficiency, considerably lower NO_x emissions than the best domestic equipment currently available, a major reduction in emissions of CO and VOCs, and lower capital costs. The technology could be used to retrofit an existing 15,000 MW of capacity as well as be used for new capacity additions. The program is attempting to help U.S. gas turbine manufacturers to become the first to commercialize this technology and capture a major share of the \$100+ billion worldwide market.

PARTNERS:

Solar Turbines, AlliedSignal, DuPont
Lanxide, Kyocera, ANL, Norton
Advanced Ceramics, Sundstrand
Power Systems, Carborundum, NGK,
ARCO, University of Dayton,
Caterpillar, Babcock & Wilcox

OIT COST: \$14,000,000
INDUSTRY COST-SHARE: \$5,000,000

ENERGY SAVINGS: 36.6 trillion Btu/yr in 2010

ENVIRONMENTAL BENEFITS: 2.1 million tons waste/yr in 2010

COST SAVINGS: \$175 million/yr in 2010

EMPLOYMENT: 930 jobs (new base) in 2010

CONTACT: Pat Hoffman (202-586-6074)

OIT IS SPONSORING THE DEVELOPMENT OF INNOVATIVE NEW TURBINE SYSTEMS FOR INDUSTRY.

Helping to Reduce the Cost of Nitrogen Oxide Cleanup

Whether used to raise steam, power turbines and engines, melt metals and glass, or heat and dry finished products, all fuels used for heat and power in the industrial sector undergo combustion. Combustion is the rapid chemical combination of oxygen and a fuel that results in the release of heat and by-product gases. Accurate control of the combustion process is a critical factor in determining energy efficiency, emissions, and product quality in the materials and process industries.

According to the Gas Research Institute, the total quantity of fuel burned in combustion equipment to generate industrial process heat and steam was 15 quads in 1990. This is about two-thirds of the energy used by industry. Thus, even a small increase in combustion efficiency could have a major impact on the total quantity of fuel used nationally. Similarly, in that same year, EPA estimated that U.S. industrial fuel combustion generated 3.3 million tons of NO_x emissions, 3.1 million tons of SO₂ emissions, 677,000 tons of CO emissions, 135,000 tons of VOC emissions, and 240,000 tons of particulate emissions. Again, improvements in the emissions characteristics of industrial burners and combustion systems could have an extremely positive effect on the nation's environment.

Reducing Nitrogen Oxide Emissions: The Key Combustion Technology Driver

While burner manufacturers and users have traditionally focused on improving combustion system efficiency and control, recent attention has focused on reducing emissions from combustion processes to avoid costly and inefficient postcombustion controls.

The basis for most air pollution policies and regulations in the United States during the past two decades has been the Clean Air Act and its amendments, referred to collectively as CAAA. Of the many provisions of the 1990 CAAA, among the most significant for industry are those related to the attainment of National Ambient Air Quality Standards (NAAQS) and control of such air pollutants as ozone, CO, fine particulate matter, SO₂, NO_x, and lead. Perhaps the most difficult of these to achieve has been the standard for ground level ozone. This ozone is formed in the atmosphere through a photochemical reaction from reactive hydrocarbons (i.e., VOCs) and NO_x. Federal programs prior to 1990 focused on controlling VOCs,

but the CAAA requires control of NO_x as well as VOCs in ozone nonattainment areas. Because NO_x is a by-product of all combustion processes, this requirement will have a major effect on industry. Many processes that have little or no emissions of such pollutants as particulates or SO₂, may for the first time require emission controls.

The Terms of Nitrogen Oxide Reduction

The Clean Air Act Amendments of 1990 (CAAA) are the primary drivers in the trend toward reducing NO_x emissions from industrial combustion equipment. While the timing and application of new rules are still being determined in many localities, a set of consistent terms has been established to describe general levels of compliance that could be required. For each level of compliance, the determination of the emission control options that must be used is based on available data on technical feasibility, availability, and demonstration of actual NO_x reduction. The terms and their definitions are as follows.

- *Reasonably Available Control Technology (RACT)* — Applies to existing emission sources above a defined NO_x emission threshold in ozone or NO_x nonattainment areas. The cost of control options is considered.
- *Lowest Achievable Emission Rate (LAER)* — Applies to new emission sources above a defined NO_x emission threshold in ozone or NO_x nonattainment areas. Defined as the greatest reduction technically achievable regardless of cost.
- *Best Available Control Technology (BACT)* — Applies to new NO_x emission sources in attainment areas. A case-by-case evaluation usually based on a top-down evaluation of emission reduction relative to a cost-effectiveness threshold.

COMBUSTION SYSTEMS

How Nitrogen Oxide Is Formed

NO_x is formed via three mechanisms:

- *Thermal NO_x* — When intense heat causes atmospheric nitrogen and oxygen to combine
- *Fuel NO_x* — When nitrogen bound in the fuel combines with oxygen in combustion air
- *Prompt NO_x* — When fuel hydrocarbons break down and recombine with atmospheric nitrogen

Although the actual provisions of the CAAA are complicated, the general thrust of the NO_x or ozone provisions is as follows.

- Specific deadlines for nonattainment areas to attain the standards have been set. Dirtier areas are given longer time to comply with NAAQS.
- States are required to revise implementation plans to include the new controls mandated in the CAAA.
- More facilities, including many small businesses, will be under control requirements in State implementation plans than in the past.
- Control technologies and feasible controls will be reexamined in light of new technology and experience with that technology.
- Different levels of control are called for under different conditions (i.e., RACT, LAER, and BACT) as discussed in the box on page 92. For existing sources, the control requirements may be limited to relatively easy-to-implement combustion modifications, such as low NO_x burners or flue gas recirculation. However, for new sources or sources in areas with more serious nonattainment problems, expensive postcombustion controls, such as selective catalytic reduction or selective noncatalytic reduction, may be required.

Control of combustion emissions, especially NO_x, promises to be costly to U.S. industry for the foreseeable future. Improved, low-cost combustion systems that can meet stringent emission standards without the need for costly, inefficient postcombustion cleanup would allow industry to invest in productivity-enhancing technologies that would promote economic growth. Hence, government and industry have strong incentives to jointly pursue advanced, very low emission combustion technology.

OIT's combustion program pursues advanced technology that will ultimately lead to improved energy efficiency, reduced emissions, increased productivity, and enhanced fuel flexibility across a wide range of industries. The program is aimed at understanding and controlling the physical and chemical processes of combustion, in order to build a knowledge base that can be applied by industry to meet specific needs. Program activities are currently focused on the aluminum, forest products, glass, petroleum refining, and steel industries.

Approaches to Nitrogen Oxide Reduction

Very low levels of NO_x emissions can be obtained with cost-effective modifications. The following describes some of the approaches under investigation by DOE and industry:

- *Low Excess Air* — Reducing the amount of combustion air provided to the flame can lower peak temperatures and reduce thermal NO_x.
- *Staged Combustion* — Adding fuel and air in stages can also reduce peak flame temperatures leading to lower NO_x formation.
- *Flue Gas Recirculation* — Recirculating flue exhaust gases, which have less oxygen than air, can be used to keep the peak flame temperature down, reducing NO_x.
- *Oxygen/Fuel Combustion* — Using "industrial" oxygen in place of air for combustion can lower NO_x emissions because no nitrogen is available to form NO_x. Combustion products cool below the NO_x formation temperature before leaving the exhaust stack.
- *Surface-stabilized Combustion* — When a gaseous fuel is burned in a porous ceramic or metallic matrix, combustion is spread out over a large area, lowering the temperature and reducing thermal NO_x formation. Also, the surface radiates well, transferring heat to the load, further lowering the temperature and NO_x formation.

SELECTED OIT COMBUSTION SYSTEMS R&D PROJECTS

VERY LOW EMISSION COMBUSTION SYSTEMS

Approximately 80% of U.S. industry is located in ozone nonattainment areas where the level of ozone exceeds the maximum set by the Clean Air Act. Emissions of NO_x contribute to the formation of this harmful ozone, not to be confused with the protective ozone layer found much higher. Although the transportation and electric utility sectors are responsible for the majority of NO_x emissions, emissions from industrial combustion are significant, representing about one-sixth of total U.S. NO_x emissions. New, low-cost combustion technologies are needed to help industry reduce its levels of NO_x emissions to comply with existing regulations and even stricter regulations expected in the future.

In the most critical of these ozone nonattainment areas, industrial expansion cannot occur without emissions offsets and industrial combustion systems that meet the tightest NO_x emission standards. Currently, these targets can be met only by using costly, energy-inefficient postcombustion systems. The goal of these four projects is to produce a new generation of low-cost, low-emissions combustion systems capable of meeting the most stringent emission standards without the use of postcombustion controls.

PARTNERS:	Alzeta, Institute of Gas Technology, Praxair, Thermo Power
OIT COST:	\$4,132,000
INDUSTRY COST-SHARE:	\$2,028,000
CONTACT:	Gideon Varga (202-586-0082)

OIT is helping several burner manufacturers develop and test low- NO_x burner systems for a variety of industrial applications. The burner systems will most likely be aimed at combustion processes in the petroleum refining, chemical, steel, aluminum, metal casting, glass, and pulp and paper industries. The companies involved have already performed much of the necessary research; OIT's support is needed for system development and for testing and evaluation at industrial host sites in preparation for technology commercialization. All of the burner systems being developed have NO_x emission levels lower than 9 parts per million, significantly lower than current low NO_x burners.

ADVANCED POROUS RADIANT BURNER

Radiant burners are used in a variety of boilers, furnaces, dryers, and other industrial and commercial combustion equipment. Their ability to heat efficiently and uniformly, without the potential for localized overheating, as well as their relatively low emissions make them desirable in many applications. The development of low-emission radiant burners enabling heating process temperatures of as much as 1800°F could have significant impact in high-temperature industries such as metals processing and petrochemicals.

OIT is currently sponsoring the development of an advanced, gas-fired, porous radiant burner that will extend radiant burner benefits to higher temperature processes. These burners produce low emissions of NO_x and CO while maintaining their high combustion efficiency. A new high-temperature burner material has been identified and patented. A six-month full-scale test has been completed successfully in a system that destroys VOCs generated by chemical processing. Even before this test was completed, a sale was made for VOC destruction and other sales have been made for paper dryers. The contractor is also offering burners made from the new material for conventional, lower temperature applications in boilers, for example. In this environment, an extended warranty can be offered.

PARTNERS:	Alzeta, Air Products and Chemicals, ECI Semiconductor
OIT COST:	\$1,494,000
INDUSTRY COST-SHARE:	\$352,000
ENERGY SAVINGS:	4.3 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	122 thousand tons waste/yr in 2010
COST SAVINGS:	\$11 million/yr in 2010
EMPLOYMENT:	20 jobs (new base) in 2010
CONTACT:	Gideon Varga (202-586-0082)

SELECTED OIT COMBUSTION SYSTEMS R&D PROJECTS

BURNER ENGINEERING RESEARCH LABORATORY

The Clean Air Act Amendments of 1990 require industry to reduce emissions of combustion by-products into the atmosphere. The challenge to industry is to find a cost-effective way to comply with these regulations while at least maintaining and preferably increasing current levels of combustion efficiency. OIT is helping industry meet this challenge by jointly funding (with the Gas Research Institute) the Burner Engineering Research Laboratory (BERL), a national test bed (a user facility) for new gaseous fuel burner designs.

BERL is available for use by burner manufacturers and other researchers who can use its state-of-the-art diagnostic facilities to collect data on the performance of their burner designs. The laboratory provides the flexibility to test a large variety of burner configurations, providing technical information previously unobtainable. For example, the first industrial user of the BERL completed a four-month burner investigation. The BERL diagnostics identified an area of high NO_x formation in the flame of Hauck Manufacturing's StAR II (Staged Air, Recirculating) burner, which is designed for high-temperature processes such as heat treating and glass and aluminum melting. The burner was modified and NO_x emissions were reduced by 20%. In many cases, the results of experiments conducted at BERL are used in conjunction with computer models to identify the reasons for pollutant formation in a variety of commonly used industrial burners. This information can then be used to modify burner designs and operating parameters to reduce emissions from such burners.

PARTNERS:	Sandia National Laboratories, Gas Research Institute
OIT COST:	\$450,000 annually
INDUSTRY COST-SHARE:	\$490,000 annually
CONTACT:	Gideon Varga (202-586-0082)

WORKPIECE TEMPERATURE ANALYZER

One method of determining the temperature of a workpiece (such as a metal sheet, slab, plate, or part) in a heat treating furnace is to measure the temperature of its surface. Current surface temperature methods, however, are limited in their applications and accuracy. Furnace control based on the internal (bulk) temperature of the workpiece would be much more accurate and could result in major operating cost and energy savings through better process control and scrap minimization.

A project is currently under way to develop a noncontact commercial system that can determine workpiece surface and/or bulk temperature using laser techniques. One laser is used to initiate sonic waves through the workpiece; another laser detects the arrival of the waves at a set location. The detection of the wave arrival is used to determine the speed of the wave through the given material, which is a function of its temperature and/or metallurgical state. The noncontact nature of this measurement makes it useful in a variety of heat treating applications. The analyzer system is a rugged, simple, and low-cost instrument that can be operated by unskilled personnel in dirty, hot, and dusty industrial environments. The ability of the system to obtain real-time measurement data will permit better process control, improved product quality, and reduced manufacturing cost. It has been estimated that these benefits translate into as much as 20% improvement in production rate and 10% reduction in energy use in steel heat treating processes.

PARTNERS:	Surface Combustion, Textron Systems, Babcock & Wilcox, John Hopkins University, Textron Defense Systems
OIT COST:	\$1,602,000
INDUSTRY COST-SHARE:	\$446,000
CONTACT:	Gideon Varga (202-586-0082)

CONTINUOUS FIBER CERAMIC COMPOSITE MATERIALS

The Potential of Ceramic Materials

Many opportunities for improving the productivity, energy efficiency, and environmental performance of industry are not pursued because of a shortage of materials capable of performing in severe operating conditions. Yet materials that are lighter, stronger, more corrosion resistant, and able to perform at higher temperatures could improve productivity in many industries by utilizing higher process temperatures, extending component and system lifetimes, and reducing downtime for maintenance and repair. While a number of advanced materials have been developed in recent years to meet these demanding requirements, ceramics offer the best combination of reduced weight, high-temperature performance, and corrosion resistance.

Ceramic products have been produced and used for thousands of years. Such ceramic products as bricks, pottery, and cement have been used for so long because their raw materials are abundant and cheap and their unique molecular structures give rise to many outstanding and highly useful properties. In addition to being as strong as or even stronger than metals, ceramics are also lighter. They possess exceptional heat, chemical, and abrasion resistance and provide excellent electrical insulation.

Industrial systems using ceramic components could be substantially more productive than those using metals. However, ceramics are brittle, which can cause catastrophic failure during service. While metals bend, ceramics break.

Fiber Reinforcement Helps Ceramic Materials Achieve Their Full Potential

Ceramic composites help overcome this serious limitation. They are not only strong, they are also tough. By incorporating continuous glass or ceramic fibers in a ceramic matrix, both the

toughness of ceramics and their ability to perform in high-stress environments can be improved substantially. Fibers help control or even eliminate ceramics' major limitation — brittleness. Because of these enhanced properties, continuous fiber ceramic composites (CFCCs) offer the potential to meet materials needs across a broad spectrum of industrial applications.

Successful deployment of CFCC components in industrial applications would help improve energy efficiency, increase productivity, and reduce environmental impacts. For example, using CFCCs in the demanding environments of incineration systems could help alleviate the waste disposal problem, decrease the toxicity of airborne pollution, and displace fuel consumption through enhanced waste energy recovery. Using CFCC components could enable gas turbines to operate at higher temperatures, thereby increasing energy efficiency by as much as 4%, which would help reduce fuel use by up to 13%. Other potential productivity- and performance-enhancing industrial applications of CFCCs include, but are not limited to

- Industrial burners and combustors ranging from small-scale space-heating units to large-scale industrial systems
- Process equipment — such as reformers, reactors, and high-pressure heat exchangers — for use in industries such as the chemical and petroleum refining
- Filters and separation systems
- High-temperature industrial heating (such as immersion and radiant heating tubes) and melting and heat treating equipment (such as furnace linings, crucibles, racks, and kiln furniture)
- Structural components such as beams, hangers, panels, decking, and containers

The CFCC R&D Agenda

The potential energy, economic, and environmental benefits of CFCCs in so many applications provide strong incentive for government and industry to jointly pursue aggressive development and deployment of these materials. The CFCC R&D agenda is driven by cost competitiveness and product reliability, which remain the overwhelming concerns of potential users and suppliers.

To produce CFCCs that are consistent in composition and reliable in performance, processing techniques must produce a uniform matrix throughout the volume of the preformed fiber component. In addition, the processing techniques must accommodate not only the matrix and fiber, but must produce the required fiber-matrix interface, which is critical to obtaining desired toughness and performance. Traditional and newly developed fabrication techniques have been used to produce CFCCs with varying success, but none has emerged as clearly superior in its ability to produce desired properties at minimum

Figure 4-3. Potential U.S. Markets for CFCCs in 2010

(*) Low temperature

(+) High temperature

Source: CFCCs for Low Cost Energy and a Cleaner Environment, RMC

CONTINUOUS FIBER CERAMIC COMPOSITE MATERIALS

costs. In fact, a variety of fabrication techniques may be desirable, with each one having advantages for specific applications.

Efforts that focus on developing cost-effective processing technology for industrial applications are needed. Advanced composite designs, standardization of test procedures, joining techniques, and prototype demonstrations are also necessary to ensure that this promising material reaches its market potential. Specific technical needs for CFCC development and commercialization include the following:

- *Fabrication and Processing Improvements* — Developing cost-effective, reliable fabrication techniques compatible with commercial and industrial needs and operations. Areas of focus include
 - High yield to achieve lower production costs.
 - Near-net-shape fabrication to minimize finishing steps.
 - Fabrication of complex shapes, including 3-D fiber architectures.
 - Scale-up to production part size and rates.
- *CFCC Materials Characterization* — Establishing a materials database on properties, performance, and life expectancy. Such a database is necessary to understand and apply CFCC materials.
- *Composite Design* — Establishing a better understanding of crack propagation and failure. Developing design models for predicting performance and properties and their relationship to processing. Developing better fiber coatings and fiber-matrix interfaces.
- *Standardization of Test Procedures and Data* — Developing comprehensive standardized procedures for design, evaluation, qualification, and testing to encourage the use of CFCCs by the engineering community.

- *Joining* — Developing the joining and fastening techniques necessary to integrate CFCCs into systems where attachment to other parts and materials is required.
- *Prototype Demonstrations* — Establish a successful performance and reliability history for CFCC applications in industrial settings.
- *Fiber Development* — Providing more environmentally stable (oxidation and corrosion resistant), higher temperature (greater than 1000°C) fibers at greatly reduced costs (less than \$200/pound).

How Fibers Improve the Toughness of Ceramics

In continuous fiber ceramic composites (CFCCs), the ceramic matrix provides chemical and thermal stability while the fiber contributes strength and toughness. The fibers provide toughness by arresting and bridging cracks through a phenomenon known as pullout. When a crack reaches a fiber, it must divert around the fiber — a process that consumes more energy than linear crack growth. Typically, there is not enough energy for the crack to change direction and bypass the fiber. Crack growth is thus arrested.

If there is sufficient energy to deflect around the fiber, the fiber can bridge the crack and hold the matrix together. Even if the matrix fails, the fibers must be pulled out before the composite separates. Fibers give rise to a noncatastrophic failure mode similar to that of metals. The arresting and bridging of cracks and fiber pullout are the principal mechanisms responsible for the increased toughness of continuous fiber ceramic composites.

SELECTED OIT CONTINUOUS FIBER CERAMIC COMPOSITE R&D PROJECTS

CFCC COMPONENTS FOR LAND-BASED GAS TURBINES

Current gas turbines used in power generation applications (excluding marine and aircraft applications) have large cooling requirements, typically requiring 30% to 40% of their discharge air for component cooling. This lowers the energy efficiency of the turbine, thus increasing its fuel requirements. Replacing metal alloy components with CFCC components could substantially increase this energy efficiency by allowing the turbine to operate at higher temperatures without cooling. The problem to date has been developing a CFCC and a corresponding fabrication method that could be used to make the components in the required shapes.

One of the new materials — called Toughened Silcomp™ — has been developed for just such applications by an industrial team under OIT's CFCC Program. Toughened Silcomp™ consists of a continuous network of silicon carbide fibers within a silicon-carbide matrix. This material and its fabrication technique — known as melt infiltration — can be used to produce a variety of fully dense, complexly shaped parts. The material's density gives the composite oxidation resistance, high thermal conductivity, low thermal expansion, and strength — all desirable characteristics for gas turbine applications. Another CFCC material is being produced by a directed metal oxidation process (DIMOX). This CFCC material will benefit applications that require thermal shock resistance, high fracture toughness, and excellent elevated temperature stability. Additionally, these CFCC components could increase gas turbine efficiency by 2%.

Using the CFCC components, gas turbines will be capable of operating at higher temperatures, reducing cooling requirements and allowing the turbine to operate more efficiently. Because of operational improvements, emissions of CO, NO_x, and unburned hydrocarbons will be reduced. It has been estimated that using the CFCC components would yield fuel savings of nearly \$1 million per year for a 100MW gas turbine.

PARTNERS:	General Electric, Textron Specialty Materials, Carborundum, DuPont Lanxide Composites
OIT COST:	\$1,490,000
INDUSTRY COST-SHARE:	\$471,000
ENERGY SAVINGS:	20 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	1.27 million tons/yr in 2010
COST SAVINGS:	\$48 million/yr in 2010
EMPLOYMENT:	210 jobs (new base) in 2010
CONTACT:	Merrill Smith (202-586-3646)

SELECTED OIT CONTINUOUS FIBER CERAMIC COMPOSITE R&D PROJECTS

CFCC PUMP COMPONENTS

Common motor pumps are typically used in chemical processing and petroleum refining plants. Typical uses are the handling of hazardous liquids in low-pressure processes up to a maximum temperature of 450°C. These pumps integrate the pump and the motor, thereby eliminating the requirement for the shaft seal. The motor stator is sealed from the pump process fluid by the containment shell. The process fluid being pumped circulates through the motor, lubricating the bearings and removing heat from the motor stator and rotor. The primary requirements for a CFCC in this application include high hoop strength, corrosion resistance, and low electrical conductivity.

Chemical pump components made of CFCCs will reduce power consumption and reduce hazardous fluid spills. By using polymer impregnation and pyrolysis (PIP), which utilizes low-temperature forming and molding steps typically used in organic matrix composites, both simple and complex shapes can be fabricated over a wide range of sizes. The advantage of applying the PIP approach to ceramic composite fabrication is the use of existing equipment and processing technology.

PARTNERS:	Dow Corning, Kaiser Composites, Sundstrand Fluid Handling/Aerospace, Synterials
OIT COST:	\$1,450,000
INDUSTRY COST-SHARE:	\$458,000
CONTACT:	Merrill Smith (202-586-3646)

CFCC APPLICATIONS FOR DIESEL ENGINE VALVE GUIDES

The diesel engines currently used in some industrial and agricultural applications present a significant opportunity for energy savings and emissions reductions if they are modified to use CFCC components. The energy efficiency of the diesel engine increases with elevated operating temperature. The cast-iron valve guides used in current engines cannot operate at temperatures above 300°C because of insufficient strength, resulting in valve deformation and eventual failure. These valves also require regular lubrication with commercial petroleum-based lubricants to maintain proper operation. Even if a valve could operate at higher temperatures, available lubricants develop deposits that would cause the valve to stick excessively.

A unique solution to this dilemma — a self-lubricating, CFCC diesel engine valve guide — is being investigated by a CFCC industrial team. The material being used is a chopped carbon fiber-reinforced silicon nitride. The composite valve guides are formed by cold isostatic pressing and then densified by glass encapsulation hot isostatic pressing. Prototype CFCC valve guides have been fabricated and tested in an engine and then field-tested. The valve guide will provide the required friction and wear properties along with the structural integrity to operate under extreme temperature conditions. These new guides are expected to cut particulate emissions by 25% by reducing flows of lubricants into the combustion chamber. Other benefits include improved fuel economy and increased engine reliability. The CFCC valve guide technology has the potential for cost-effective use in high-load-factor industrial and agricultural applications, where operating costs are driven by engine fuel costs, and in alternative-fueled engines. It is also possible that the technology will be used in a substantial number of future diesel engines and may eventually apply to internal combustion engines in general.

PARTNERS:	AlliedSignal, Caterpillar
OIT COST:	\$804,000
INDUSTRY COST-SHARE:	\$214,000
CONTACT:	Merrill Smith (202-586-3646)

SELECTED OIT CONTINUOUS FIBER CERAMIC COMPOSITE R&D PROJECTS

HOT GAS FILTERS

Filter systems are used in coal combustion and refinery processing in order to filter particles from a process. Hot gas filters are used for high-efficiency particulate and contaminant removal in ranges of 300° to 1000°C. Durable, long-life ceramic filter elements being developed under the CFCC Program could help industries clean process gases effectively and economically and meet the requirements of the Clean Air Act Amendments.

Babcock & Wilcox uses a liquid-to-solid-based processing method, sol-gel impregnation, to develop ceramic filters. This approach is ideal for oxide-based composite systems and allows scaling for cost-effective manufacturing. Near-term emphasis is on filters for advanced fossil energy systems.

Atlantic Research is developing a CFCC candle filter to support DOE's clean coal technology for hot gas filtration pressurized fluidized bed and coal gasification systems. Rigorous testing of representative CFCC candle filters is under way. The next tests will use simulated environments from existing power generation cycles.

Dow Corning is also assessing high-temperature filtration materials for the chemical industry's process streams.

PARTNERS:	Atlantic Research, Babcock & Wilcox, Dow Corning, DuPont Lanxide Composites, Industrial Filter & Pump Manufacturing, Westinghouse Electric
OIT COST:	\$1,643,000
INDUSTRY COST-SHARE:	\$400,000
CONTACT:	Merrill Smith (202-586-3646)

CERAMIC COMPOSITE RADIANT TUBES

The concept of using CFCC tubes in waste heat recovery and power generation applications has existed for years, but no CFCC material fit the requirements. Now, with DOE support, an industrial team is developing and demonstrating a novel method for fabricating CFCC materials needed in manufacturing low-cost tubes. The process uses various reinforcing fibers in a nitride-bonded silicon-carbide matrix. Tubes made from this material will subsequently be impregnated and coated using the unique Textron Rapid Densification (RD™) process to enhance their durability.

The new CFCC tubes are targeted for a variety of applications, including steam-methane reformers used in the chemical industry, and pyrolysis furnaces, immersion heaters, industrial burners, and preheaters used primarily in the metals processing industries. One specific application being investigated is the recovery of waste heat from melting used beverage cans and other aluminum scrap in the aluminum recycling industry.

PARTNERS:	Textron Specialty Materials, Nova Industrial Ceramics, Hauck Burner, Materials Science, MIT, IBIS, F. W. Schaefer, Doehler-Jarvis
OIT COST:	\$1,803,000
INDUSTRY COST-SHARE:	\$430,000
ENERGY SAVINGS:	2 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	164 thousand tons/yr in 2010
COST SAVINGS:	\$6 million/yr in 2010
EMPLOYMENT:	350 jobs (new base) in 2010
CONTACT:	Merrill Smith (202-586-3646)

ADVANCED INDUSTRIAL MATERIALS

Prospects for Growth at the Materials Edge

During the past three decades unprecedented progress has been made in the development of advanced materials, including advanced ceramics, polymers, metals, and composites of these materials. Typically, these materials possess properties that are far superior to those of conventional materials such as steel, aluminum, glass, plastics, wood, or paper. As shown in Figure 4-4, advanced materials are often far stronger than conventional materials. In addition, they are frequently tougher; more wear, corrosion, or heat resistant; lighter; or more efficient conductors of photons or electrons than are conventional materials. The use of advanced materials in industry can improve process efficiency and productivity through reduced life-cycle energy use, higher processing temperatures, increased component and system lifetimes, and reduced downtime.

Advanced materials are not supplied by a single industry; hence, the advanced materials industry does not consist of the relatively homogeneous group of firms that is typical of most other industries. Advanced materials are manufactured by firms in the chemicals (polymer, composite, ceramic), metal (alloys, composites, intermetallics), and traditional ceramics and glass industries. Moreover, unlike other materials industries in which scale economies dictate that large firms predominate, many advanced materials companies are small enterprises that were established to develop and sell one or a handful of highly specialized materials with superior properties.

Though markets for most conventional materials industries are fairly mature, cutting-edge technology in each of the major classes of materials is highly dynamic. For example and as indicated in Table 4-1, advanced polymers are finding

applications as nonlinear optical devices, permeable membranes, thermal and electrical insulation, fuel cells, ceramic precursors, and sensors. Advanced ceramics and composites can be used in wear parts, cutting tools, heat exchangers, refractories, gas turbines, pump seals, substrates, and machine components for industrial processing. Metals, alloys, and metal matrix composites include ductile, high-strength materials and electrical conductors that vary from structural materials, magnets, and processing equipment to motors and engines. Because of the exceptional growth potential of advanced materials, the traditional materials industries — especially the chemical, ceramics, aluminum, and specialty metals industries — have shown strong interest in the development and manufacture of these high-value-added materials.

Material Needs and Opportunities in Traditional Manufacturing Industries

Despite U.S. leadership in the development of new materials, these materials have not been widely applied in manufacturing. High cost is the main barrier to increased use of advanced materials. On a dollar-per-pound basis, advanced materials are often several times more expensive than conventional materials. Lower cost processing methods are perhaps the most important need if advanced materials are to find wider use in industry and fulfill their potential. Standardization, liability concerns, and user familiarity are among the many other barriers that impede the diffusion of advanced materials.

Using advanced materials in industry has been inhibited further because opportunities to apply these materials in many traditional manufacturing processes have not been adequately assessed. In addition, potential users are not sufficiently aware of the performance benefits of advanced materials — let alone how or where to use them. Hence, an important initial step in accelerating the movement of advanced materials into industrial usage is to conduct detailed analyses of material needs on an industry-by-industry basis.

OIT's Advanced Industrial Materials program has taken the initiative in this area and has inventoried the material needs of the pulp and paper and glass industries. Satisfying these needs could have a significant impact on improving energy efficiency, productivity, and environmental compliance in these industries. In pulp and paper, wear and corrosion — including abrasive and erosive wear, cavitation wear, sliding wear, and impact wear — are important issues because nearly every form of wear may be encountered during various processes. Replacing wear-critical components with more durable parts, inserts, or surface treatments is needed.

Figure 4-4. Strength Comparison of Traditional and Advanced Materials

ADVANCED INDUSTRIAL MATERIALS

Corrosion issues are encountered throughout all pulping and papermaking processes and remain among the most visible and costly materials issues.

Opportunities for new materials in the paper industry include

- Improved materials to provide impact-resistant edges for chipper blades, saws, and knives
- Refiner materials suitable for higher rotation rates with lower mass and higher fracture toughness for high-speed bearings
- Boiler tube materials and surface coatings with improved resistance to hydrogen sulfide and stress-assisted waterside corrosion
- Polymer-based structural materials for vessels, piping, and valves

Several material needs and opportunities have been identified in the glass industry also. Although many of the material needs in this industry are dependent on the specific end uses, overall the problems of wear, corrosion, and erosion are major concerns in the glass industry. Material opportunities in the glass industry include

- Developing new refractory materials
- Developing new coatings and deposition technologies for glasses
- Modeling metals and ceramics to analyze their survivability in corrosive atmospheres
- Developing intermetallics and coatings for glass contact applications

The application of advanced materials in areas of these industries where opportunities have been identified could help them increase product quality, satisfy emissions requirements, and improve energy efficiency. Improved materials could also lead to less downtime, more efficient manufacturing operations, and reduced operating costs. This would improve the competitiveness of U.S. glass and paper producers, increase their exports, benefit employees in these industries and have a number of other positive impacts on the U.S. economy.

Table 4-1. Characteristics and Applications of Advanced Materials

	Examples	Characteristics	Selected Applications
Ceramics and Ceramic Matrix Composites	alumina, silicon carbide, silicon nitride, molybdenum disilicide, zirconia, fiber or particulate reinforced ceramic matrix composites	light weight, high strength, high toughness, wear resistant, heat resistant, and corrosion resistant	wear parts, cutting tools, heat exchangers, refractories, gas turbines, pump seals, substrates, and machine components for industrial processing
Metals, Alloys, and Metal Matrix Composites	nickel aluminide, titanium aluminide, iron aluminide, aluminum alloys, titanium alloys, and fiber or particulate reinforced metal matrix composites	light weight, wear resistant, corrosion resistant, heat resistant, and ductile	structural materials, cutting tools, magnets, processing equipment, motors, and engines
Polymers and Polymer Matrix Composites	liquid crystal polymers, conducting polymers, nonlinear optical polymers, fiber or particulate reinforced polymer matrix composites	light weight, corrosion resistant, high strength and stiffness	nonlinear optical devices, permeable membranes, thermal and electrical insulation, fuel cells, ceramic precursors, and sensors

SELECTED OIT ADVANCED INDUSTRIAL MATERIALS R&D PROJECTS

ADVANCED METALS AND COMPOSITES

New materials that can withstand higher temperatures are needed to increase the efficiency of current industrial processes. To address these material needs, researchers are developing new alloys known as aluminides — combinations of aluminum with nickel, iron, or titanium. One alloy in particular, nickel aluminide, or Ni_3Al , has already been successfully demonstrated for applications in the heat treating and metal processing industries.

New Ni_3Al components have successfully been applied in the mechanism used to support and convey moving parts through heat treating furnaces, where metal parts such as gears and coils are heated to achieve the desired strength, toughness, and metallurgical properties. The new components have also been used in other heat treating furnace applications and as transfer rolls in steel reheat furnaces in the steel fabrication industry. The Ni_3Al components have longer lifetimes, which reduce furnace downtime; have better wear resistance and strength; permit higher furnace-operating temperatures; and increase furnace productivity. Energy savings result from the improved productivity as well as from the elimination of cooling water requirements.

Researchers are also developing intermetallic composite materials that resist fracture at high temperatures. Efforts have been focused on a material known as molybdenum disilicide (MoSi_2), which exhibits superior properties at elevated temperatures. These properties could be particularly useful in such applications as burner nozzles, gas turbine components, and heating elements for industrial furnaces.

PARTNERS:	ORNL, LANL, Bethlehem Steel, General Motors, Sandusky International, Alloy Engineering, Advanced Refractory Technologies, Owens Corning Fiberglas, Air Products and Chemicals
OIT COST:	\$1,800,000
INDUSTRY COST-SHARE:	\$1,000,000
ENERGY SAVINGS:	15.5 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	1.04 million tons waste/yr in 2010
COST SAVINGS:	\$66 million/yr in 2010
EMPLOYMENT:	660 jobs (new base) in 2010
CONTACT:	Charles Sorrell (202-586-1514)

Using MoSi_2 parts will enable such equipment to operate at higher temperatures with higher thermal efficiencies, translating directly into reduced energy requirements.

POLYMERS AND BIO-BASED MATERIALS

About 30 billion pounds of plastics end up in U.S. landfills each year. Currently, only about 2% of this waste is recycled because of the difficulties of working with different types of plastics mixed together. OIT is sponsoring a number of efforts to recover high-value chemicals from mixed waste plastics using pyrolysis, a process whereby the wastes are heated in the absence of oxygen in a closed chamber. The most successful effort to date has been the recovery of the chemical caprolactam from waste carpeting. The pyrolysis process also has the potential to recover chemicals from mixed plastic beverage bottles.

OIT is also sponsoring a variety of other polymer research activities, including the development of polymers that conduct electricity. These types of polymers have a wide range of applications in such things as electric utility equipment, electric vehicles, separation of gases during chemical processing, printed circuit boards, and automobile parts. Conducting polymers can be used as a low-cost means of storing electricity in power backup systems and in electric vehicles. They can be used to adapt membrane systems to separate specific combinations of gases. As a coating material, conducting polymers can reduce both the cost and the pollution associated with plating operations used for metallized printed circuit boards, structural components for cars, and

PARTNERS:	National Renewable Energy Laboratory, Los Alamos National Laboratory
OIT COST:	\$2,100,000
INDUSTRY COST-SHARE:	\$2,000,000
COST SAVINGS:	\$10 million/yr in 2010
EMPLOYMENT:	140 jobs (new base) in 2010
CONTACT:	Charles Sorrell (202-586-1514)

coated plastic parts. Finally, novel processing methods based on the use of magnetic fields are being investigated for possible use in separating chemicals and also making lightweight parts for cars.

SELECTED OIT ADVANCED INDUSTRIAL MATERIALS R&D PROJECTS

ADVANCED CERAMICS AND COMPOSITES

For at least three decades, titanium diboride (TiB_2) has been known to be suitable to use as the cathode in the Hall-Heroult electrolytic cells used to convert molten alumina to aluminum metal. OIT has sponsored a variety of research efforts to develop TiB_2 ceramic cathodes. As part of the development of any new material, researchers must determine the most efficient processing method for manufacturing that material. This means applying or adapting existing materials processing methods or coming up with entirely new methods. As part of OIT's cathode research, scientists have been investigating the use of chemical vapor infiltration to fabricate high-purity TiB_2 without damaging the ceramic fibers themselves.

Like the TiB_2 fabrication effort above, OIT's other research efforts in advanced ceramics seek to exploit the advantageous properties of ceramics (their resistance to high temperatures and corrosion) while limiting or overcoming their disadvantages (brittleness, quality control problems, and limitations in fabrication techniques). For example, researchers are investigating a process known as reactive metal infiltration to produce near-net-shape (meaning that minimal additional grinding or finishing is required) ceramic composites for lightweight structural and wear applications. In reactive metal infiltration, the brittle ceramic is reacted with a molten metal and is converted into a tough metal-ceramic composite.

PARTNERS:	Oak Ridge National Laboratory
OIT COST:	\$800,000
INDUSTRY COST-SHARE:	\$6,000,000
ENERGY SAVINGS:	60 billion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	4 thousand tons waste/yr in 2010
COST SAVINGS:	\$180 thousand/yr in 2010
CONTACT:	Charles Sorrell (202-586-1514)

Another research effort is investigating the production of low-cost, intermetallic-bonded ceramic composites for applications where severe friction and wear are present. Also under investigation is the production of composite aerogel materials (lightweight, porous materials that contain more than 90% air by volume) that improve the thermal resistance of a component by more than 50% is also under investigation.

NEW MATERIALS AND PROCESSES

Silicon carbide (SiC) is a ceramic material that can safely and reliably withstand operating temperatures many hundreds of degrees higher than metals and metal alloys can withstand. In particular, SiC is desirable for use in high-temperature heat exchangers, recuperators (used to recover waste heat), and burners used in the metals, glass, and other industries. Limitations in fabrication techniques for ceramic components have been obstacles to using these beneficial materials, however. SiC is generally difficult to produce in the lengths and shapes typically required for many industrial applications. Ceramic heat exchanger tubes are also extremely difficult to join together to make a workable heat exchanger. These problems combine to make fabricating large ceramic tube assemblies prohibitively expensive. Recent research has been investigating the use of microwave energy to advance the manufacture of ceramic components in a cost-effective manner.

In one such effort, researchers are using fabrication techniques based on microwave energy to join one SiC component to another. Microwave processing is of great interest to materials researchers, because its ability to heat material from the inside out has many technical benefits. The goal is to develop and optimize a practical joining method that can be applied to large-scale production of ceramic components such as high-temperature heat exchangers and burners. The method could also be used to make economical on-site repairs at a plant.

In another effort, researchers are exploring other new applications for microwave processing that uses a new variable frequency microwave furnace. The variable microwave process will permit more energy-

PARTNERS:	FM Technologies, George Mason University, LANL, ORNL
OIT COST:	\$2,000,000
INDUSTRY COST-SHARE:	\$1,300,000
ENERGY SAVINGS:	38 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	2.3 million tons waste/yr in 2010
COST SAVINGS:	\$142 million/yr in 2010
EMPLOYMENT:	1670 jobs (new base) in 2010
CONTACT:	Charles Sorrell (202-586-1514)

efficient processing of materials by virtue of its ability to operate at optimum frequency or at variable frequencies as the material is heated. It also generates a more uniform microwave field that allows for even heating of single and multiple parts in the furnace. Applications of this technology include producing multilayer ceramic capacitors (energy-storing devices) and processing certain plastics. The variable microwave process requires only a fraction of the energy of current processing methods and is several times faster, thereby improving productivity.

TECHNOLOGY ACCESS PROGRAMS

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NATIONAL INDUSTRIAL COMPETITIVENESS THROUGH ENERGY, ENVIRONMENT AND ECONOMICS (NICE³)

Grants for Technology Demonstration Partnerships

National Industrial Competitiveness through Energy, Environment and Economics, commonly referred to as NICE³, is a grant program which advances industrial competitiveness through cleaner manufacturing processes. NICE³ provides financial assistance to State and industry partnerships. NICE³ funds projects that will demonstrate and commercialize innovative processes and/or equipment to improve competitiveness, foster energy efficiency, and reduce waste.

The goals of NICE³ are to improve energy efficiency, promote cleaner manufacturing, and improve competitiveness in industry. To achieve these goals, DOE solicits proposals that seek to

- Encourage accelerated industrial demonstration, deployment, and dissemination of energy efficiency and cleaner manufacturing technologies
- Implement efficiency improvements in processes, material inputs, and waste streams
- Demonstrate successful industrial applications of innovative cleaner manufacturing techniques in conjunction with energy-efficient technologies
- Coordinate and integrate the activities of institutions responsible for energy, the environment, and competitiveness at the Federal, regional, State, and local levels
- Target technologies, processes, and procedures that are transferable to a broad range of applications within and across industrial sectors
- Identify and develop strategies to overcome barriers that currently inhibit energy efficiency or cleaner manufacturing techniques and practices in business and industry
- Enhance industrial competitiveness through the introduction and dissemination of cost-effective, energy-efficient, and cleaner manufacturing processes, equipment, and practices

Encouraging Innovation in

Clean Manufacturing Processes

NICE³ is implemented through a competitive solicitation process that awards grants to industry and State partnerships. Industry applicants present innovative technologies to State energy, pollution prevention, or business development offices for review, as all NICE³ grant applications must be submitted through a State office. State offices partner with companies submitting the most promising proposals to OIT for possible NICE³ funding.

NICE³ proposals should describe how application of the innovative technology would improve energy efficiency, reduce costs to industry, and prevent pollution in industries classified in SIC codes 20-39 (manufacturing). Emphasis is on projects that could be applied in the seven industries that are the focus of OIT's Industries of the Future initiative. This includes the aluminum, chemical, forest products, glass, metal casting, petroleum refining, and steel industries. The industrial applicant may receive a one-time award not to exceed \$425,000 in Federal funding for up to three years. In addition, NICE³ grant winners

NICE³ proposals are evaluated based on the following criteria:

- Concept development
- Innovation
- Energy savings
- Waste savings
- Economic competitiveness
- Commercialization potential
- Technology transfer prospects
- Applicant capabilities
- Cost breakout
- Outside resources

NATIONAL INDUSTRIAL COMPETITIVENESS THROUGH ENERGY, ENVIRONMENT AND ECONOMICS (NICE³)

are required to match Federal funds with a minimum 55% cost-share. The State applicant may use up to \$25,000 or 10% of the award total, whichever is less, to support costs associated with technology transfer and marketing. A key provision of the NICE³ program is that State and industry partners must agree to publicly share information regarding the new process or technology with industry to maximize national benefits. This is because the objective of the program is to support technologies or processes that can be commercialized or replicated within and across industries.

In the six years since NICE³ was initiated, 495 proposals have been submitted by 45 States. Currently there are 50 active projects, 12 of which have already shown success — that is, are currently selling units.

"Second Chance" Funding

A unique feature of the NICE³ program, secondary marketing of proposals, gives applicants with promising projects additional opportunities to receive funding. The NICE³ grant application includes an attachment that allows applicants to authorize OIT to pass on nonfunded (i.e., nonselected) NICE³ proposals to other R&D supporting organizations for second-chance consideration for R&D funding.

OIT has forwarded nonfunded proposals to organizations such as the Electric Power Research Institute, EnerSource Capital, Environmental Plus, and the Gas Research Institute. This program feature serves as a catalyst for involving other organizations while confirming OIT's commitment to helping industry improve competitiveness and productivity through the demonstration and deployment of advanced technologies.

ESTIMATED PROGRAM BENEFITS IN 2010

ENERGY SAVINGS:	600 trillion Btu/yr
ENVIRONMENTAL BENEFITS:	12 million metric tons/yr carbon equivalent reduction
COST SAVINGS:	\$7 billion/yr

SELECTED NICE³ TECHNOLOGY DEMONSTRATION PROJECTS

ELECTROLESS NICKEL PLATING SOLUTION

In electroless nickel plating, nickel alloys are deposited on the surface of a metal product such as an automobile or aircraft part, electric motor, or other machinery or equipment. Electroless nickel plating is superior to standard plating in the uniformity of its deposit and its ability to coat internal surfaces of parts. Efforts have been made to extend the life of the plating bath because of the process downtime and waste treatment requirements associated with limited bath life. Until now, however, little emphasis has been placed on the reforming or regeneration of the plating bath chemicals.

A new process known as the IONSEP electroless nickel process has been developed to continuously reform plating chemicals. OIT is working with the developer to design the electrodialytic equipment for a commercial-scale system in which chemicals will be reformed at the same rate at which they are depleted in the bath. The IONSEP process is expected to reform nearly 100% of the plating chemicals, conserving their embodied energy. Use of the process also eliminates the need to treat the plating waste, thereby eliminating sludge production. Continuous reforming of the bath maintains a steady bath composition and improves productivity.

PARTNERS:	Ionsep, Delaware Department of Natural Resources and Environmental Control
OIT COST:	\$250,000
INDUSTRY COST-SHARE:	\$250,000
ENERGY SAVINGS:	0.9 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	65 thousand tons waste/yr in 2010
COST SAVINGS :	\$270 million/yr in 2010
EMPLOYMENT:	2530 jobs (new base) in 2010
CONTACT:	Alan Schroeder (202-586-1641)

RECOVERY AND REUSE OF WATERWASH OVERSPRAY PAINT

The painting operations used at automotive and other types of assembly plants are often less than 50% efficient, wasting large amounts of paint. The oversprayed paint is almost always landfilled, often in the form of waterwash paint sludge. Landfilling has been necessary primarily because no cost-effective recycling alternatives have been available. The major obstacle has been the tacky nature of the agglomerated, waterwash paint waste, which presents significant handling problems.

OIT has been participating in the development of the Spangler process to recover oversprayed paint for reuse. In this process, oversprayed particles are captured and detackified without destructively altering the composition of the paint. A series of chemical and physical processes are used to prepare the paint for reuse as high-performance coatings. The demand for virgin pigment is greatly reduced with this process, lowering operating costs and saving energy. Environmental benefits include large reductions in the amount of waste paint sludge requiring disposal.

PARTNERS:	Caterpillar, Illinois Department of Energy and Natural Resources
OIT COST:	\$285,000
INDUSTRY COST-SHARE:	\$555,000
ENERGY SAVINGS:	1.4 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	670 thousand tons waste/yr in 2010
COST SAVINGS:	\$8 million/yr in 2010
EMPLOYMENT:	80 jobs (new base) in 2010
CONTACT:	Alan Schroeder (202-586-1641)

SELECTED NICE³ TECHNOLOGY DEMONSTRATION PROJECTS

MEMBRANE FILTRATION TECHNOLOGY TO PROCESS BLACK OLIVES

Black ripe olive processing generates large volumes of wastewater that are typically discharged into evaporation ponds. Tightening environmental regulations are causing processors to examine ways to recycle water and chemicals cost-effectively. One recycling method being investigated is membrane filtration — specifically ultrafiltration and reverse osmosis — combined with evaporation and drying to yield useful by-products.

OIT, in cooperation with a black ripe olive processor, is developing the membrane filtration process to treat 1 million gallons/day of process water and then recycle it back into the olive-processing operation. The by-products from the process include olive pomace, which will be used as a fuel in a biomass cogenerator, and a dried by-product that may be used as animal feed. Energy savings will be achieved through recycling of water, reduction of chemical usage, and production of biomass for boiler fuel. Waste production will also be greatly reduced, contributing to lower plant operating costs.

PARTNERS:	Tri Valley Growers, California Energy Commission
OIT COST:	\$425,000
INDUSTRY COST-SHARE:	\$6,936,000
ENERGY SAVINGS:	1.7 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	18 million tons waste/yr in 2010
COST SAVINGS:	\$205 million/yr in 2010
EMPLOYMENT:	840 jobs (new base) in 2010
CONTACT:	Alan Schroeder (202-586-1641)

ATMOSPHERE GAS RECOVERY AND REGENERATION IN HEAT TREATING OPERATIONS

Carburization is a heat treating operation commonly used by manufacturers to produce case-hardened surfaces on steel parts for automobiles and a variety of heavy equipment. Parts to be carburized are placed in high-temperature furnaces in the presence of gaseous carbon monoxide (CO), which is typically mixed with hydrogen and nitrogen. The current industry practice is to discharge the furnace atmosphere gases directly into ambient air, with no attempt at recycling, reuse, or energy recovery. Heat recovery is seldom considered because of the toxicity of the discharged gases.

OIT is cooperating with industry in the installation of a full-scale prototype of a new technology to recover, clean, and reuse over 90% of the current furnace atmosphere gas at a carburizing facility. The atmosphere recovery and regeneration process uses commercially available membrane technology to remove the impurities from the gas. The recovered gas will be returned to the furnace as a replacement atmosphere, eliminating the need for the energy intensive thermal catalytic generation of new atmospheres. Emissions of CO and of nitrogen and sulfur oxides would be reduced to below currently mandated thresholds.

PARTNERS:	Dana, Minnesota Department of Public Service
OIT COST:	\$269,000
INDUSTRY COST-SHARE:	\$455,000
ENERGY SAVINGS:	2.7 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	240 thousand tons waste/yr in 2010
COST SAVINGS:	\$7.2 million/yr in 2010
EMPLOYMENT:	90 jobs (new base) in 2010
CONTACT:	Alan Schroeder (202-586-1641)

SELECTED NICE³ TECHNOLOGY DEMONSTRATION PROJECTS

CULLET GLASS FEEDSTOCK PURIFICATION USING ADVANCED OPTICAL SORTATION

The U.S. glass industry is looking for ways to help it compete more effectively with other packaging industries. The use of waste glass, or cullet, as feedstock presents an opportunity for glass manufacturers to reduce costs and increase production. However, cullet often contains ceramic contaminants, particles that cannot be separated from the glass except by hand. The appearance of these contaminants in the final product causes the product to be rejected; in some cases, rejected containers compose 15% of production.

A new optical ceramic sortation technology that removes ceramic and other contaminants from cullet has been developed with funding from OIT. The contaminants are detected by optical sensors and removed by computer-controlled jets of compressed air. The new technology will increase the use of cullet by glass manufacturers, saving energy because cullet has a lower melting temperature than virgin glassmaking ingredients. In addition, the raw materials demand for glassmaking will be reduced, as well as landfilling of cullet.

PARTNERS:	Alpine Technologies, Oregon State University, Oregon Department of Energy
OIT COST:	\$348,000
INDUSTRY COST-SHARE:	\$958,000
ENERGY SAVINGS:	6.6 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	630 thousand tons waste/yr in 2010
COST SAVINGS:	\$18 million/yr in 2010
EMPLOYMENT:	210 jobs (new base) in 2010
CONTACT:	Alan Schroeder (202-586-1641)

INNOVATIVE DESIGN OF A BRICK KILN USING LOW THERMAL MASS TECHNOLOGY

Kilns are widely used to fire clay products, such as brick and pipes, and to fire enamels on metal products. Few technological advances have occurred in clay product firing and control despite the relative inefficiency of most kilns and the large quantities of pollutant emissions associated with their operation. One brick manufacturer is currently investigating an innovative kiln design that combines low thermal mass (LTM) technology with state-of-the-art controls, combustion technology, and monitoring equipment.

OIT is participating in the investigation of the new kiln technology, which will use approximately half of the natural gas to fire the same weight of brick. The use of the LTM materials will allow the kiln design to be optimized from an operations standpoint. The superior thermal characteristics of the LTM materials, together with the configuration of the new kiln and its improved control features, will save time (both cold start-up time and firing time) and increase operating flexibility. The improved controllability of the kiln will also result in fewer rejected products.

PARTNERS:	Pacific Clay Brick Products, California Energy Commission
OIT COST:	\$350,000
INDUSTRY COST-SHARE:	\$2,846,000
ENERGY SAVINGS:	52 trillion Btu/yr in 2010
ENVIRONMENTAL BENEFITS:	3 million tons waste/yr in 2010
COST SAVINGS:	\$580 million/yr in 2010
EMPLOYMENT:	1320 jobs (new base) in 2010
CONTACT:	Alan Schroeder (202-586-1641)

INVENTIONS AND INNOVATION PROGRAM

Technical and Financial Assistance for Independent Inventors

OIT's Inventions and Innovation Program is the only Federal effort devoted to technical and financial assistance for independent inventors. Individuals who solve an energy-related problem or develop an innovative energy-saving or energy-production technology can benefit from the technical and financial assistance offered by OIT.

OIT manages several activities that provide funding and commercialization training to develop energy-saving inventions for small businesses and independent innovators and inventors. The Innovative Concepts Program assists inventors in the early stages of concept development; the Energy-related Inventions Program assists inventors during any stage of invention development. The Commercialization Planning and National Innovation Workshops educate inventors about the process of technology commercialization. These programs and workshops fill a critical void for independent inventors in need of credibility and venture capital.

Innovative Concepts Program

The Innovative Concepts Program (InnCon) provides assistance in the early stages of the invention process, when innovators are just beginning to develop their concept. The program essentially provides seed money for innovators to use for determining if their energy-related ideas are technically and economically feasible. Through the InnCon Program, inventors receive assistance in locating technical partners, commercial sponsors, and additional funding sources. InnCon also helps innovators promote their ideas to Government agencies, businesses, and industries.

InnCon operates in cycles of up to two years, during which program participants receive both financial and technical assistance. For each cycle, the program solicits proposals from innovators for funding novel projects related to a specific energy-related topic, especially those of interest to OIT's Industries of the Future teams. Proposals are reviewed to ensure the applicant is qualified and the proposal meets general InnCon requirements. Up to 20 innovators receive awards at a maximum amount of \$22,000 to research the technical and economic feasibility of their projects. InnCon also solicits funding from other Federal sources that may benefit from the InnCon projects. Partnering with other agencies can increase the number of grants that InnCon is able to provide and the visibility of the projects, thus enhancing the inventors' potential to commercialize the product.

Each InnCon cycle provides innovators the opportunity to present their work to business and industrial representatives. Innovators also attend a Commercialization Planning Workshop designed to provide professional guidance in planning how to move innovations and inventions to the marketplace. Topics addressed in the workshop include

- Selecting a commercialization strategy
- Analyzing markets for new technologies
- Locating sponsors
- Raising capital
- Licensing

While the InnCon Program assists inventors in the early stages of inventing original energy-related technologies, the program is not intended to fund improvements in existing technologies. However, InnCon-supported inventions may lead to additional support through the Energy-related Inventions Program.

Energy-related Inventions Program

Jointly sponsored by OIT and the U.S. Department of Commerce's National Institute of Standards and Technology (NIST), the Energy-related Inventions Program (ERIP) is designed to reduce commercialization barriers for the energy-related inventions of independent inventors, small businesses, and universities. ERIP provides

- Technical evaluation (at no cost to the inventor)
- Consideration for grant funding
- A market assessment
- Commercialization training

INVENTIONS AND INNOVATION PROGRAM

To enter ERIIP, an inventor must submit a technical description of the invention and a two-page form containing background information on the inventor and/or small business. Submissions are independently evaluated for technical feasibility and energy impact by NIST senior engineers, who are supported by a network of independent consultants from universities and private practice. If NIST considers the invention to be "promising" — that is, technically feasible, having significant energy conservation or supply potential, and economically or commercially practical — NIST conducts a second-stage evaluation.

The second-stage evaluation is a more in-depth analysis that serves to confirm the "promising" rating received during the initial assessment. If the invention passes the second evaluation, the NIST evaluator prepares a formal report recommending that DOE consider funding the inventor for up to \$100,000 for innovative research and technical development. If the invention receives an unfavorable evaluation, the inventor may submit additional information in response to what NIST refers to as "technical flaws" and request that NIST reevaluate the invention.

After NIST recommends an invention for funding, the inventor is assigned an OIT Invention Coordinator. The inventor is required to submit a proposal to the Invention Coordinator detailing how and by whom the work will be performed, as well as the desired outcome. The Invention Coordinator develops options for supporting the invention based on the NIST evaluation, the inventor's proposal, and the OIT market analysis. The Invention Coordinator also discusses the support options with the inventor and assists the inventor with developing a statement of work describing how OIT funding will be used.

Since program inception, documented benefits of the Inventions and Innovation Program include

- Saved 1 quad of energy (enough energy to supply 10 million households for a year)
- Reduced pollution by 5.1 million metric tons of carbon emissions
- Created or sustained 4000 jobs

ESTIMATED PROGRAM BENEFITS IN 2010

ENERGY SAVINGS: 90 trillion Btu/yr
ENVIRONMENTAL BENEFITS: 27,000 metric tons/yr NO_x reduction

ERIIP is an ideal resource for inventors who need help commercializing a product. ERIIP participants, like InnCon participants, attend a Commercialization Planning Workshop designed to help inventors develop strategies to move their technologies into the marketplace. Classes address

- Patents
- Licensing
- Business planning
- Market analysis
- Financing
- Other issues directly related to successfully commercializing new technologies

National Innovation Workshops

Small business inventors are introduced to the fundamentals of developing and commercializing new technologies at National Innovation Workshops. The two-day seminars, a cooperative effort of Federal and regional programs, provide inventors with the opportunity for one-on-one interaction with expert presenters. Topics discussed at these seminars include

- Patent protection
- Licensing and marketing
- New business start-up
- Business plan development
- R&D and venture financing
- Small Business Innovation Research program

Since the Inventions and Innovation program began in 1974, approximately 24% of the technologies recommended by NIST to OIT for funding have reached the marketplace. This is a rate comparable to that of private sector venture capital. This equates to over 4000 jobs either created or sustained by these market entries. Over this same period, program assistance has resulted in almost \$30 million in licensing royalties and more than \$1 billion in invention sales.

SELECTED INVENTIONS AND INNOVATION PROGRAM PROJECTS

LOW PROFILE FLUID CATALYTIC CRACKER

Catalytic crackers are used by petroleum refiners to convert crude oil into higher-value fractions. "Cat crackers" are typically very large, with capacities up to 100,000 barrels per day (bpd). Conventional catalytic cracker designs cannot economically be scaled down below 10,000 bpd, leaving small refiners at a competitive disadvantage.

A new catalytic cracker design ideally suited for small refineries has been investigated with financial help from DOE. The design is a modular unit that can be expanded in increments of roughly 1000 bpd of crude-oil capacity. A new unit based on this design would cost much less to construct because of its low profile and the elimination of the large, tower-type structure used with conventional cat crackers. Operating and maintenance costs and energy requirements would also be reduced. Because of its modularity and economics, the new design could help small refineries compete effectively with large refineries.

PARTNERS: Dr. Milton Thacker, Process Innovators
DOE COST: \$89,500
CONTACT: Fred Hart (202-586-1496)

HYDRODYNAMIC DEFLECTION PAD BEARINGS FOR MULTIPLE APPLICATIONS

Bearings are machine components used to position other components, such as shafts or rotors, so they can move only in their intended mode. In shoe-type bearings, the active face of the bearing consists of pivoting shoes or pads. The result is a low-friction bearing capable of carrying high loads. Unfortunately, these high-performance bearings tend to be rather expensive.

An innovative, low-cost variation of the shoe-type bearing has been developed in cooperation with DOE. Each shoe or pad on this bearing, known as the KMC bearing, is mounted on a flexible structure that optimizes its performance. The KMC bearing can be made very small for its load-carrying capacity, particularly when used with a rotating shaft. Energy savings result from reduced friction between the bearing and the shaft or other component. Motors and other machines incorporating the new bearing can be designed with tighter tolerances, improving their efficiency and cost-effectiveness.

PARTNERS: Russell Ide, RMC
DOE COST: \$75,000
CONTACT: David Crouch (202-586-4844)

CARBON-FIBER REINFORCED COMPOSITES

Graphite is a form of carbon consisting of layers of atoms. Bonding is strong between atoms of the same layer and weak between atoms of different layers. When graphite undergoes a process known as exfoliation, the distance between the carbon layers is increased, reducing the material's density. Exfoliation yields high-strength graphite fibers, which can be used in the synthesis of composite materials that are strong yet lightweight. Although some composite materials that use graphite fibers are commercially available, applications of these composites are limited because of brittleness and bonding problems.

Working with a materials inventor, DOE has developed a method for producing a novel form of graphite fibers known as graphite ribbon. The surface of the ribbon is corrugated, providing a good bond between the graphite and the other materials used in the composite. The ribbon-shaped fibers have also exhibited unusually high ductility, which leads to greatly improved impact strength. Composite materials made with these ductile fibers have potential applications as electrical and thermal conductors, and in the aerospace and other industries.

PARTNERS: Dr. Deborah Chung, State University of New York at Buffalo
DOE COST: \$96,000
CONTACT: Fred Hart (202-586-1496)

SELECTED INVENTIONS AND INNOVATION PROGRAM PROJECTS

ENERGY EFFICIENT, ELECTRIC ROTARY FURNACE FOR GLASS MOLDING (REPRESSING) PRECISION OPTICAL BLANKS

The gas-fired furnaces conventionally used in the production of precision optical blanks lose more than 90% of the heat energy of their fuel up the exhaust stack. Additional energy losses occur during heat-up cycles that are less than optimal because of their reliance on operator judgment. Variations in the heat-up cycle can also have a detrimental effect on product quality.

A new electrically heated rotary furnace for glass molding of precision optical blanks has been developed with DOE support. Because the electric furnace does not use an exhaust stack, it is much more energy efficient than gas-fired furnaces. The heat-up cycles for over a thousand types of glass can be automated with the new furnace, leading to increased operating flexibility, production capacity, and product quality. The technology also has potential applications in other industrial and commercial sectors.

PARTNERS: DarLyn Pochan
DOE COST: *In procurement*
CONTACT: Fred Hart (202-586-1496)

THERMAL HEAT AND DIFFUSION TREATMENT OF BULK POWDERS

Heat treating processes are used to improve the physical properties of metal and metallized ceramic parts. Vacuum heat treating ovens are commonly used because the presence of oxygen during heat treating can cause undesirable surface reactions. Temperature uniformity throughout the part being treated is crucial to optimizing the part's desired metallurgical properties. Although careful temperature control is possible with a number of modern vacuum ovens that incorporate special heater and control systems, these ovens are expensive and have large space requirements.

With DOE support, a new heat treating machine has been developed that is smaller and less expensive than conventional vacuum ovens. The machine consists of a fluidized bed of spheroidal ceramic powder contained in a cylindrical retort. In operation, the retort is rotated and the ceramic powder particles transfer heat from the retort walls to the part being treated. The unit provides more rapid heating and cooling,

PARTNERS: Willard Kemp
DOE COST: \$100,000
CONTACT: Fred Hart (202-586-1496)

improving energy efficiency and productivity. The technology is expected to benefit small machine shops and foundries that cannot afford the larger conventional ovens.

MOLTEN FILM HIGH-INTENSITY PAPER DRYER

The dryer section of a paper machine has high thermal energy requirements because it uses steam-based dryers to reduce the moisture content of the paper. Because a large number of these dryers are required for a single machine, dryer sections are very capital intensive. No revolutionary changes have occurred in paper drying technology since the early part of this century.

DOE has been supporting the investigation of a technology that represents a totally new method of drying paper. In the new process, the wet paper web is passed through a high-temperature, eutectic molten metal bath where it picks up a layer of the molten metal. The high temperature causes the water in the paper web to boil, forming steam that strips away part of the water film on the opposite side of the web. The solidified film of metal is separated from the surface of the paper and recycled to the melter. This new invention could yield significant savings in the capital costs and energy requirements associated with paper drying.

PARTNERS: David Walter Warren
DOE COST: \$100,000
CONTACT: Fred Hart (202-586-1496)

MOTOR CHALLENGE

One Billion Motors Currently in Use...

Electric motors and the systems they power perform vital roles in just about every niche of the U.S. economy. More than one billion electric motors are currently in use in industrial, commercial, residential, and utility power plant applications, consuming huge amounts of energy.

Motor-driven equipment accounts for approximately 70% of the electricity consumed in the industrial sector, and in some industries represents 90% of electricity consumption. Industrial electric motor systems (EMS) account for more than 20% of total U.S. electricity consumption and nearly 40% of the electricity used in EMS in all sectors.

U.S. electric-motor-driven system equipment sales total roughly \$20 billion annually and about 200,000 people are involved in the manufacture of the system components. Roughly \$30 billion is spent on electricity to drive industrial motor systems.

...Represent a Huge Opportunity for Energy Savings, Emissions Reductions

The widespread use of EMS throughout U.S. industry provides significant opportunities to capture broad-based benefits associated with more efficient EMS. Besides the potential for substantial energy savings, increases can be made in productivity. Reduced energy use and changes made in processes associated with the system can also result in lower emissions and reduced waste streams, thereby improving environmental quality while reducing costs associated with waste remediation.

There are four major opportunities to improve the efficiency of electric motor systems. Together these improvements could potentially save over 100 billion kWh annually by the year 2010.

These include

- Improving the efficiency of the motor
- Reducing losses associated with electricity distribution
- Improving the match between the motor drive and the mechanical system
- Using equipment or processes that require less power (process optimization)

Efficient EMS on average use 20% less energy than conventional systems. Although initial capital costs are higher for an efficient system, efficient EMS offer increased reliability over conventional technology. The bottom line is that using more efficient EMS can result in lower costs to industry and increased competitiveness.

Electric Motor Systems Defined

Electric motor systems include the motor, the electric supply system that provides electric energy to the motor; the motor starting control and drive system; the driven mechanical system such as fans, pumps, blowers and compressors; and the process application (Figure 5-1).

Electric power is the input to the system, and the output is the service or process application provided (for example, refrigeration, airflow, or material movement).

Figure 5-1. The Electric Motor System (EMS)

MOTOR CHALLENGE

The electric motor changes electric energy into mechanical power to perform work and is the core of EMS. However, the motor is only one of many factors that contribute to the efficiency of an electric motor system.

Other factors include the efficiency of other individual components of the electric motor system (such as the controlling devices, pumps, fans and compressors) and how the individual components are integrated into a complete system.

High-efficiency EMS require the optimal integration of motors and drives with the power supply, as well as with the process application. Industrial EMS are often integrated into complex manufacturing operations in which productivity, quality, and energy factors need to be considered carefully.

OIT's Principal Customer Industries Are Heavy Motor Users

The materials and process industries account for over one-half of all electricity used in manufacturing motor systems. These industries — which include the chemical, petroleum, forest products, metals, and glass industries — offer major opportunities for improvement in the use of efficient motor systems.

For example, in the pulp and paper industry, motor systems account for 95% of electricity consumed, with the potential to reduce electricity consumption by 11% to 49% through the use of energy-efficient measures, according to the American Council for an Energy Efficient Economy (ACEEE). Potential electricity savings in the chemical industry are similar, ranging from 11% to 44%.

In addition to the industries already mentioned, other industries in which significant electricity savings are possible through energy-efficient motor systems include primary metals, transportation equipment, rubber and plastics, and electrical equipment, according to ACEEE.

Barriers to Adoption of More Efficient Electric Motor Systems

However, a number of barriers must be overcome to achieve more widespread adoption of efficient EMS. These barriers include these facts:

- *The Electric Motor System Market Is a Cost-dominated Market* — Companies often do not look beyond the initial purchase cost in deciding which motor to purchase, even though long-term savings could be substantial.
- *The Motor Often Accounts for a Small Portion of the Total System Cost* — Thus, the importance of the motor is often overlooked.
- *The Efficiency of Existing Motors Is Often Not Known* — The efficiency rating of a motor can be reduced substantially through successive repairs. Likewise, users many times do not opt for the more efficient, newly purchased motor that offers better life-cycle cost than an existing motor in need of repair.
- *The Structure of the Electric Motor System Market Is Complex* — Fragmentation in the market makes it difficult for a user to obtain sufficient, reliable information on the markets and end-use applications of motor systems. In addition, because motors are often components of larger systems, equipment manufacturers — not end-users — often determine motor specifications.
- *Many End-users Lack Technical Expertise* — Because many users lack sufficient experience or expertise in EMS, they do not always make the best technology choices. This is exacerbated by misinformation in the marketplace concerning efficient EMS.

Motor Challenge Enables Industry to Overcome Barriers to Adoption of More Efficient EMS

To help industry overcome these barriers by enabling individual firms to more easily identify and take advantage of energy savings in electric-motor-driven systems, OIT created its Motor Challenge Program in 1993. As part of President Clinton's Climate Change Action Plan (CCAP), the Motor Challenge Program is recognized as representing a significant opportunity to enhance environmental performance and reduce energy consumption in U.S. industry.

Figure 5-2. Total Net Electricity Demand by Manufacturing Industries, 1994

Note: Net electricity demand is defined as purchases, on-site generation, and net transfers of electricity, less quantities sold.

Source: EIA estimates

MOTOR CHALLENGE

The overall goal of the Motor Challenge initiative is to advance industry leadership and provide technical assistance and resources to industry so that firms will better understand, apply, and target energy-efficient EMS from a systems perspective.

In most cases the technology already exists to use efficient EMS. Motor Challenge was designed to act as a catalyst to foster broad-based industrial participation in the exchange of information and the deployment of technology.

OIT has worked diligently with stakeholders to identify barriers and opportunities related to the adoption of more efficient EMS. The program works with partners to focus on deficiencies in the market that influence the choices of stakeholders in specifying, purchasing, and operating equipment and impede the development and introduction of better products and services.

Working through a partnership ensures that the OIT program reflects the needs and opportunities of all aspects of EMS, including design, manufacture, selection, purchase, operation, and maintenance. Numerous activities take place through the partnerships, including information exchange, conferences, seminars, and training. Partnership activities initially focused on the motor and drive elements of EMS, but focus is shifting to barriers and opportunities associated with pumps, fans, blowers, and compressors.

These partnership activities and related marketing and deployment initiatives are being coordinated with DOE regional support offices, users, suppliers, distributors, utilities, as well as other organizations. Nearly 1700 organizations joined as partners through the end of fiscal year 1996, and have been participating in regional and national information exchange activities.

The major objectives of Motor Challenge are as follows.

- Provide national leadership and help focus public and private capabilities to assist U.S. industrial motor system end-users in achieving greater cost-effective energy efficiency, productivity, and environmental performance more quickly than they otherwise would
- Provide objective and reliable information and technical knowledge to industrial end-users by drawing on the experiences of industrial leaders in EMS
- Discover and promote engineering excellence in the design and operation of EMS and encourage other companies to follow these examples

- Support development of decision tools and educate and train practitioners and trainers in the latest best practices associated with efficient EMS
- Assess EMS markets to improve the timeliness and reliability of data on such systems
- Support industry partnerships to develop and implement market transformation strategies that will encourage demand for better products and services
- Recognize and support companies that have implemented internal corporate management practices and policies for efficient motor-driven systems in an exemplary and high-quality manner

The Motor Challenge initiative consists of six basic elements: (1) Allied Partner activities, (2) Excellence Partner activities, (3) showcase demonstrations, (4) the Information Clearinghouse, (5) decision tools, and (6) industry partnerships.

Allied Partner Activities

Motor Challenge recognizes the benefits of working with companies and organizations that routinely provide products and services to industry. Those companies are in an excellent position to educate industrial end-users about opportunities to improve the efficiency of their electric motor systems. As of the end of fiscal year 1996, over 50 Allied Partners have joined the program.

Allied Partners have access to a broad array of Motor Challenge publications, decision tools, etc., which they distribute to industrial end-users in the course of their daily business or in conjunction with customer education meetings or workshops.

Excellence Partner Activities

Motor Challenge Excellence Partners are motor users that have made a commitment to continually improve their motor systems management practices. They participate in the program in a manner that is best suited to their day-to-day operation and overall energy policies and management strategies. Program participants need not have achieved excellence, but they must commit to continuously improving their motor-driven systems management practices and strive toward excellence.

MOTOR CHALLENGE

Motor Challenge and the Excellence Partner each has a clearly defined role. The Excellence Partner designs and implements a motor systems improvement plan that is economically beneficial to the company. Motor Challenge acts as a facilitator, providing resources such as consulting assistance, tools, training resources, and marketing assistance to corporate headquarters to encourage plant sites to participate in the program. The Motor Challenge program assists its Excellence Partners in achieving excellence.

Showcase Demonstrations

Showcase demonstration projects show that the energy efficiency potential of EMS can be achieved cost-effectively. The projects are implemented by industrial teams led by end-users who may partner with others (e.g., utilities, suppliers, etc.). Motor Challenge provides technical assistance and tools to help the teams

- Develop better strategies to implement the project
- Validate costs and benefits
- Establish strategic alliances
- Gain recognition for their efforts

Over 30 showcases have been selected to date. Thus far, the OIT independent performance validation process has confirmed paybacks of less than 1.5 years. In addition, the validated annual electricity savings from the first two completed projects (Lockheed Martin Armaments and 3M) is over 1.5 million kWh/year. These validated results and the lessons learned in the projects should encourage replication in other facilities and compound the energy savings.

Information Clearinghouse

The Information Clearinghouse became operational in February 1994 and serves as a one-stop shop to provide interested parties easy access to a variety of resources. During FY 1996, the clearinghouse received over 5000 requests for information and assistance.

The clearinghouse distributes credible and unbiased information and decision-making tools, as well as education and training materials. It also provides technical assistance, manages a World Wide Web homepage and an electronic bulletin board, as well as publicizes upcoming conferences and workshops.

ESTIMATED PROGRAM BENEFITS IN 2010

ENERGY SAVINGS:	140 trillion Btu/yr
ENVIRONMENTAL BENEFITS:	2.2 million metric tons/yr carbon equivalent
COST SAVINGS:	\$1.9 billion/yr

Decision-making Tools

The Motor Challenge Program supports the development of design-decision tools, best practices, and guidelines on various electric motor system applications. Computer software products available include MotorMaster and MotorMaster+.

These software programs will provide the user with a listing of motors, from motor manufacturers, with motor efficiencies and unit cost for a set of input parameters (e.g., required power and rotational speed). MotorMaster+ provides this function in a Windows environment with several added features.

In addition, Motor Challenge has developed a series of training modules. Each module can be used independently or as part of other education and training activities.

Industry Partnerships

In collaboration with various organizations — such as the Compressed Air and Gas Institute, the Electrical Apparatus and Service Association, and the Hydraulic Institute — Motor Challenge is developing a variety of instructional and informational products. The objective is to assist Motor Challenge partners with making more informed decisions regarding the design specifications, and maintenance of electric motor systems.

In addition, DOE is working with industry to develop and define key EMS market and technology opportunities while coordinating its R&D activities with other motor-related technology initiatives.

CLIMATE WISE

Encouraging Voluntary Actions to Achieve a Cleaner Environment

Climate Wise, a partnership program jointly sponsored by the OIT and EPA, is designed to reduce greenhouse-gas (GHG) emissions through voluntary implementation of energy-efficiency measures. Climate Wise provides businesses with the information they need to adopt strategies and technologies that will improve their bottom lines while protecting the environment.

Climate Wise is not an R&D program. Rather, it tries to encourage the use of available but not widely used technologies and practices that can cut energy use and cost, reduce emissions and wastes, and improve productivity. It focuses on getting industry to voluntarily undertake actions that will help narrow the gap between standard and best practice in industry. To help facilitate these actions by industry, Climate Wise provides its partners access to several resources, including

- Guidance in developing an action plan
- Leads to economic and technical resources
- Access to other Federal programs
- Information tools and manuals
- Workshops and seminars
- Opportunity for public recognition

Currently, there are 129 Climate Wise partners, representing 6% of U.S. industrial energy use.

Climate Wise is a component of the Climate Change Action Plan (CCAP), a series of initiatives to help the United States honor its international commitment to reduce GHG emissions to 1990 levels by the year 2000.

Partnering to Protect the Environment While Improving Productivity

By joining the Climate Wise partnership program, industry leaders pledge to implement cost-effective, voluntary actions to decrease their companies' emissions. Climate Wise partners are encouraged to

- Participate in other CCAP programs, such as Motor Challenge, Waste WiSe, or Green Lights
- Develop their own strategies to reduce emissions
- Pledge to implement their strategy in conjunction with one of the CCAP programs

Companies are also encouraged to (1) incorporate supportive management actions such as publishing a corporate policy declaring energy efficiency and environmental protection a company priority; (2) solicit employee input; and (3) designate an energy management team of key personnel from engineering, management, marketing, and financial departments.

To become a Climate Wise partner, a company must sign an agreement that commits it to identifying and subsequently implementing cost-effective energy-efficiency and pollution prevention actions. Within six months of becoming a partner, the company must submit a Climate Wise Action Plan detailing the company's strategy to initiate, expand, or accelerate measures to improve energy efficiency, reduce emissions, and prevent pollution.

The Climate Wise Action Plan is an organization's strategy to reduce GHG emissions in a cost-effective manner. The plan includes optimization strategies such as upgrading equipment and processes; utilizing fuel switching methods such as cogeneration, eliminating waste heat, and using renewable energy; and integrating efficiency into product design and manufacturing. The Climate Wise program offers guidance in devising the action plan.

Financial and Technical Resources Available to Climate Wise Partners

Climate Wise has also developed a portfolio of financial and technical resources available to its partners. Financial resources include Small Business Administration guaranteed loans, low-interest buy-downs from State providers, State tax credits, and private sector sources. Low-interest loans for up to \$250,000 are available for eligible Climate Wise partners through partnerships with various State energy offices.

Technical resources are also available to Climate Wise partners. These include

- Industrial Assessment Centers
- Federal agencies
- National Laboratories
- Public utilities
- Trade associations
- State and local offices dealing with energy, pollution prevention, and economic development

These organizations will help with opportunity assessments, design and implementation of projects, and collecting and tracking of energy and emissions data.

Two manuals have been developed to assist Climate Wise partners: *The Climate Wise Opportunities Assessment Guide* and the *Climate Wise Case Study Compendium*.

The Climate Wise Opportunities Assessment Guide contains an extensive list of practical actions that companies of all sizes have implemented to save money, improve productivity, and protect the environment. The guide is useful for companies that have resources available to audit themselves. It contains a detailed list of energy-efficiency and pollution prevention projects and a simple worksheet to assist companies with a self-evaluation.

The Climate Wise Case Study Compendium explains how companies are benefiting from the implementation of improved energy-efficiency and pollution prevention technologies and business practices. It is designed for Climate Wise partners looking to adopt technologies or practices that have already been successfully demonstrated in industry. The compendium describes a number of pollution prevention success stories and provides financial and technical details.

Climate Wise-sponsored workshops and seminars bring together experts from industry, Government, R&D organizations, and financial institutions to find creative ways to improve industrial efficiency. Partners participate in business-to-business exchange workshops to learn how other companies have improved their profitability, productivity, and environmental performance.

Climate Wise also cosponsors showcase GHG reduction demonstration projects that can be replicated by other companies.

CLIMATE WISE

Public Recognition

Public recognition for implementing energy savings and pollution prevention technologies improves a company's public image and boosts workplace morale.

Hence, Climate Wise publicly recognizes partners that achieve and record results. Recognition is awarded to companies for emissions reduction, technology breakthroughs, and continuous improvement. To qualify for recognition, companies must report their results through the Energy Policy Act of 1993 (EPACT) Voluntary Reporting Program, Section 1605(b).

Companies may participate in a range of recognition programs such as national and local signing ceremonies and awards programs, media events, published announcements in national magazines, and other promotional activities. Ceremonies will be tailored to meet the recipients' needs.

A growing number of companies are discovering that the goals of improved profitability and competitiveness are not in conflict with an environmentally conscious way of doing business — they are mutually dependent. In fact, companies pursuing energy-efficiency and pollution prevention projects stand to gain a competitive edge over businesses that fail to make these adjustments.

ESTIMATED PROGRAM BENEFITS IN 2010

ENERGY SAVINGS:	87 trillion Btu/yr
ENVIRONMENTAL BENEFITS:	1.4 million metric tons/yr carbon equivalent
COST SAVINGS:	\$1.6 billion/yr

A Climate Wise Success Story

The Kelly Company of Clinton, MA, a leading source of injection molded and structural foam parts for paint and hardware industries, was a productive and profitable player in the industry for many years. But in the mid-1980s, the national recession and international competition brought the company to the brink of financial disaster.

Seeking to cut costs without eliminating jobs, the company focused on reducing energy costs, its third largest expense. With the assistance of the Massachusetts Electric Company and the Massachusetts Industrial Services Program, Kelly received a special loan of \$150,000 and utility rebates of \$130,000 for energy-efficiency improvements based on the results of a detailed energy audit.

By implementing the recommended energy-saving measures, Kelly's electricity costs were reduced by 20% — an annual savings of \$83,000. Annual reductions of 1.5 million pounds of CO₂ and 16,000 pounds of SO₂ also resulted.

INDUSTRIAL ASSESSMENT CENTERS

No-Cost Energy and Environmental Audits for Small and Medium-Sized Manufacturers

Small and medium-sized manufacturing plants employing between 20-500 employees each and having gross sales of less than \$75 million comprise over 30 percent of all manufacturing establishments and 56 percent of manufacturing employees in the United States.

Depending on the industry, energy costs for small and medium-sized plants can account for ten percent or more of their operating costs. In addition to the financial cost, energy use contributes to environmental pollution and the waste of natural resources. Inefficient operating systems also impact global competitiveness.

In operation for 20 years, OIT's Industrial Assessment Center program addresses the needs of this critical segment of the U.S. economy by conducting industrial assessments at no cost to the manufacturer. On average, these assessments help individual manufacturers identify cost savings of \$55,000/year while increasing productivity and preventing pollution.

To receive a no cost assessment from the Industrial Assessment Center Program, a manufacturing plant must:

- Fall into Standard Industrial Codes 20-39
- Be located within 150 miles of an Industrial Assessment Center
- Have gross sales below \$75 million
- Employ a maximum of 500 employees at that plant site
- Have annual energy bills below \$1,750,000
- Lack the professional staff to do these analyses

What's an Assessment?

Under the guidance of experienced faculty, a team of engineering students sponsored by the Department of Energy is inserted into manufacturing facilities that meet certain criteria (see box) to conduct a no-cost assessment.

When the team arrives at the plant, it meets with the managers to take an initial tour of the facility. Team members ask various questions about procedures and identify potential areas of efficiency improvement. Once the team completes the initial tour, it will go back through the plant carefully to take measurements and collect data.

The team analyzes the energy use and environmental aspects of the plant's operation, following the process from the raw material phase through manufacturing and product distribution. For example, the team members will measure the temperature of rooms where the air compressors are housed. They will check the load of the compressor to make sure it's operating at peak performance. They will check the lighting to see if illumination is sufficient and to make sure ballasts are properly installed and if so, to determine whether unused ballasts can be removed. They will measure the composition of flue gas in boilers to determine efficiency. Other equipment and systems which will receive a thorough analysis include chillers, motors, pumps, fans, furnaces, burners, insulation, ventilation, and heating and cooling. The team will also evaluate the building, including the roof and the grounds. Other routine, yet often overlooked, opportunities for energy savings will be investigated, including turning off equipment when not in use, installing back doors on thermostats controlling space heating, recycling, compacting trash to reduce waste disposal fees, and minimizing water waste.

An exit briefing to the plant management provides an opportunity for the plant to screen out recommendations that are impractical to implement because of technical or quality considerations.

The assessment generally entails a one-day site visit. Once half of the data has been obtained, the assessment team returns to the university and prepares a formal report outlining its findings and recommendations about how the plant could optimize its equipment and processes for energy efficiency, waste minimization, and productivity improvements.

The report to the plant estimates the cost to implement each recommendation and the potential savings and payback time. The team will follow up with the plant after six to nine months to assess implementation and savings actually realized by the client plant.

INDUSTRIAL ASSESSMENT CENTERS

IACs Can Reach Manufacturers in 43 States

There are currently 30 Industrial Assessment Centers in operation at accredited engineering schools. Managed by universities, these centers are able to reach manufacturers in 43 states. Universities are competitively selected and are qualified to conduct both energy-efficiency and waste minimization and productivity assessments.

The benefits of industrial assessments go well beyond the cost savings and productivity enhancements achieved by individual manufacturers. Companies around the Nation benefit from the data through student training and an Industrial Assessment Center database available to the public via the Internet.

Training Engineers

Each Center trains about 4 to 12 students per year. Nationwide the program annually graduates about 150 students trained in energy and waste management and productivity improvement. These students find employment at many manufacturing facilities across the country, where they continue to disseminate efficiency and pollution prevention skills and experience. To date about 1700 engineering students have been trained through the program.

Database

In addition to serving the needs of the manufacturers qualified to receive the no-cost assessments, the information accumulated through 20 years of experience is available to benefit all manu-

ESTIMATED PROGRAM BENEFITS IN 2010

ENERGY SAVINGS:	124 trillion Btu/yr
ENVIRONMENTAL BENEFITS:	1.4 million metric tons/yr carbon equivalent
COST SAVINGS:	\$1.4 billion/yr

facturers through a database maintained at Rutgers University. The database can be accessed through the Internet at http://oipea-www.rutgers.edu/html_docs/dbase.html.

The results of over 6000 energy audits and close to 1000 industrial assessments, which include waste data, are included in the database. The data provide information about each manufacturer receiving an assessment, including the type of manufacturing done at the plant, plant size, products, and manpower. For proprietary reasons, company name and location are not included in the database. The data include assessment recommendations, which recommendations were actually implemented, and what the costs and payback were for the company.

In addition to the historical assessment data, three useful publications — a self-assessment workbook, a training manual, and a productivity manual — are also downloadable from the database.

Publications Available

For those interested in conducting their own internal audits, the self-assessment workbook provides small manufacturers with a set of procedures for improving operations and reducing costs. The workbook outlines the general procedure for performing assessments and provides the information and calculations necessary to implement or assess several specific cost-saving projects common to most operations. The manual lists the average plant's major energy-consuming equipment and

Fig. 5-2. Department of Energy Industrial Assessment Center Locations

INDUSTRIAL ASSESSMENT CENTERS

gives 21 specific recommendations and anticipated cost savings from implementation.

The training manual is a useful and comprehensive tool for providing technical training to a range of potential end-users interested in performing industrial assessments at small- to medium-sized manufacturing plants. Unlike the self-assessment work-

book, the training manual does not contain a list of top 20 recommendations that any small facility can conduct. Rather, it is an in-depth analysis of systems and equipment found in many plants and contains the details necessary to optimize each one for energy efficiency and pollution prevention. In like fashion the productivity manual provides comprehensive data on productivity improvement actions and technologies.

INDUSTRIAL ASSESSMENT CENTER CONTACTS

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Georgia Institute of Technology
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University of Louisville
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DETAILED ECONOMIC DATA AND METRICS ESTIMATION METHODOLOGIES

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Table A-1. Salient Economic Statistics for the Materials and Process Industries, 1994

Industry	SIC Code	Employment (thousands)	Value of Shipments (billions)	Value Added (billions)	Capital Expenditures (millions)	Average Wages (\$/hour)	Purchased Energy (millions)	Pollution Abatement Costs (millions)
<i>Lumber and Wood Products</i>	24	718.5	\$103.6	\$40.7	\$2,547.8	\$9.61	\$1,789.0	\$549.6
<i>Paper and Allied Products</i>	26	621.4	\$143.8	\$63.3	\$7,311.7	\$14.33	\$6,209.4	\$2,561.3
Forest Products — Total		1,339.9	\$247.4	\$104.0	\$9,859.5	\$11.77	\$7,998.4	\$3,110.9
Chemical and Allied Products	28	824.0	\$333.3	\$181.2	\$15,455.0	\$16.20	\$10,487.6	\$7,138.2
Petroleum Refining	2911	71.7	\$128.2	\$23.2	\$5,215.2	\$21.64	\$3,612.7	\$5,400.7
<i>Flat Glass</i>	321	11.2	\$2.6	\$1.7	\$137.1	\$19.01	\$193.2	\$22.6
<i>Glass and Glassware</i>	322	63.1	\$9.6	\$6.2	\$583.4	\$15.17	\$696.1	\$124.3
<i>Products of Purchased Glass</i>	323	58.2	\$7.9	\$4.3	\$268.3	\$11.03	\$172.1	\$38.4
<i>Mineral Wool</i>	3296	19.8	\$3.7	\$2.2	\$122.2	\$15.28	\$263.6	\$99.3
Glass — Total		152.3	\$23.9	\$14.3	\$1,111.0	\$13.96	\$1,325.0	\$284.6
<i>Blast Furnaces and Steel Mills</i>	3312	156.1	\$50.6	\$20.7	\$2,614.8	\$20.72	\$3,571.0	\$1,318.7
<i>Steel Wire and Related Products</i>	3315	25.3	\$5.1	\$2.4	\$170.1	\$12.33	\$142.5	\$23.5
<i>Cold Finishing of Steel Shapes</i>	3316	15.1	\$6.5	\$2.1	\$198.1	\$18.11	\$144.5	\$63.4
<i>Steel Pipes and Tubes</i>	3317	24.6	\$6.3	\$2.1	\$148.3	\$13.87	\$117.2	\$25.0
Steel — Total		221.1	\$68.5	\$27.3	\$3,131.3	\$18.83	\$3,975.2	\$1,430.6
<i>Primary Aluminum</i>	3334	19.4	\$5.2	\$1.8	\$167.1	\$18.52	\$1,252.9	\$171.5
<i>Aluminum Sheet, Plate, and Foil</i>	3353	22.2	\$10.6	\$2.7	\$272.9	\$19.03	\$324.6	\$77.4
<i>Aluminum Extruded Products</i>	3354	29.2	\$5.1	\$2.1	\$146.7	\$11.18	\$145.3	\$30.1
<i>Aluminum Rolling and Drawing</i>	3355	1.0	\$0.6	\$0.2	\$6.4	\$15.67	\$11.8	\$4.0
Aluminum — Total		71.8	\$21.5	\$6.7	\$593.1	\$15.45	\$1,734.6	\$283.0
<i>Iron and Steel Foundries</i>	332	122.9	\$14.0	\$8.2	\$547.2	\$14.20	\$789.7	\$327.5
<i>Nonferrous Foundries</i>	336	81.6	\$8.7	\$4.9	\$418.6	\$11.43	\$304.6	\$53.1
Metal Casting (foundries) — Total		204.5	\$22.7	\$13.1	\$965.8	\$13.12	\$1,094.3	\$380.6
Materials and Process Industries — Total		2,885.3	\$845.4	\$369.9	\$36,330.9	\$13.91	\$30,227.8	\$18,028.6
Total Manufacturing	20-39	18,343.9	\$3,340.2	\$1,598.5	\$112,000.4	\$12.40	\$61,531.3	\$28,550.0
Materials & Process Industries — % of Mfg.		15.73%	25.31%	23.14%	32.44%	112.18%	49.13%	63.15%

Sources: 1994 Annual Survey of Manufactures, Bureau of the Census; Pollution Abatement Costs and Expenditures 1994, Bureau of the Census

Table A-2. Employment Data for the Materials and Process Industries by State, 1994 (thousands)

	Aluminum	Chemical	Forest Products	Glass	Metal Casting	Petroleum Refining	Steel
AL	4.8	13.7	51.3	1.0	8.7	w	6.7
AK	w	w	2.5	w	w	w	w
AZ	3.4	4.8	12.4	w	w	w	w
AR	3.5	6.8	35.8	w	1.4	w	3.7
CA	6.3	58.7	90.0	15.1	10.3	11.3	5.7
CO	w	3.0	7.5	w	w	w	2.0
CT	5.9	14.9	9.2	w	w	w	1.9
DE	w	5.6	3.0	w	w	w	w
DC	w	w	w	w	w	w	w
FL	1.7	18.7	33.9	5.2	w	w	1.7
GA	6.7	18.9	59.4	3.7	w	w	2.6
HI	w	w	w	w	w	w	w
ID	w	3.5	12.8	w	w	w	w
IL	11.2	50.9	48.0	9.5	12.0	4.5	18.3
IN	10.9	21.5	40.6	9.0	15.1	w	33.9
IA	w	8.2	14.0	w	3.8	w	w
KS	w	8.0	9.4	2.3	2.0	1.6	w
KY	5.2	13.5	19.9	4.9	2.0	w	5.0
LA	w	28.0	24.5	w	w	8.8	w
ME	w	w	25.7	w	w	w	w
MD	w	13.2	13.1	w	w	w	w
MA	4.4	16.0	24.4	4.1	w	w	1.0
MI	4.2	30.9	36.0	8.2	19.4	w	12.6
MN	w	8.5	37.7	w	4.7	w	1.2
MS	3.0	6.6	37.1	w	w	w	1.0
MO	3.1	19.8	20.8	1.0	5.2	w	2.5
MT	w	w	6.9	w	w	w	w
NE	w	2.8	4.1	w	w	w	w
NV	w	w	1.6	w	w	w	w
NH	2.1	1.2	8.4	w	1.6	w	w
NJ	4.6	67.0	23.7	10.1	1.9	2.3	2.2
NM	w	1.5	2.7	w	w	w	w
NY	9.6	42.2	48.6	9.3	2.6	w	4.6
NC	8.4	40.3	66.3	10.7	1.2	w	1.8
ND	w	w	1.2	w	w	w	w
OH	6.8	42.2	52.8	19.9	28.2	2.0	37.5
OK	w	3.7	7.7	1.7	1.8	1.7	1.5
OR	1.2	3.0	58.5	w	3.7	w	1.0
PA	11.9	29.6	63.4	16.8	13.9	4.1	38.0
RI	3.1	2.1	2.5	w	w	w	1.3
SC	2.8	40.9	29.8	w	1.1	w	2.9
SD	w	w	2.1	w	w	w	w
TN	4.9	35.5	40.4	3.3	7.0	w	2.7
TX	11.7	77.9	60.8	8.6	10.6	19.7	7.5
UT	1.0	4.0	6.0	w	w	w	w
VT	w	w	5.3	w	w	w	w
VA	2.8	21.7	38.8	3.3	3.4	w	w
WA	8.4	5.2	46.7	1.1	2.2	1.7	w
WV	2.7	13.0	9.0	3.9	w	w	8.1
WI	1.6	11.0	75.7	4.1	20.9	w	1.9
WY	w	1.1	1.5	w	w	w	w

Source: 1994 Annual Survey of Manufactures, Bureau of the Census

w = data withheld or not applicable

Bold figures indicate the 10 States with the largest number of employees for each industry.

Table A-3. Payroll Data for the Materials and Process Industries by State, 1994 (million \$)

	Aluminum	Chemical	Forest Products	Glass	Metal Casting	Petroleum Refining	Steel
AL	\$185	\$537	\$1,490	\$34	\$258	w	\$280
AK	w	w	\$83	w	w	w	w
AZ	\$105	\$126	\$266	w	w	w	w
AR	\$93	\$229	\$916	w	\$30	w	\$136
CA	\$198	\$2,230	\$2,481	\$481	\$278	\$619	\$245
CO	w	\$110	\$188	w	w	w	\$76
CT	\$205	\$797	\$310	w	w	w	\$77
DE	w	\$240	\$81	w	w	w	w
DC	w	w	w	w	w	w	w
FL	\$47	\$651	\$869	\$131	w	w	\$62
GA	\$239	\$680	\$1,748	\$145	w	w	\$85
HI	w	w	w	w	w	w	w
ID	w	\$145	\$340	w	w	w	w
IL	\$396	\$2,345	\$1378	\$267	\$380	\$249	\$771
IN	\$377	\$928	\$994	\$279	\$535	w	\$1,644
IA	w	\$276	\$382	w	\$142	w	w
KS	w	\$276	\$210	\$102	\$52	\$75	w
KY	\$182	\$549	\$464	\$145	\$55	w	\$205
LA	w	\$1,376	\$750	w	w	\$510	w
ME	w	w	\$862	w	w	w	w
MD	w	\$508	\$349	w	w	w	w
MA	\$142	\$694	\$773	\$145	w	w	\$34
MI	\$193	\$1,352	\$1,113	\$285	\$742	w	\$605
MN	w	\$294	\$1,209	w	\$154	w	\$50
MS	\$79	\$236	\$890	w	w	w	\$28
MO	\$99	\$681	\$563	\$30	\$133	w	\$100
MT	w	w	\$185	w	w	w	w
NE	w	\$94	\$111	w	w	w	w
NV	w	w	\$43	w	w	w	w
NH	\$68	\$46	\$229	w	\$61	w	w
NJ	\$152	\$3,174	\$745	\$299	\$64	\$145	\$93
NM	w	\$48	\$47	w	w	w	w
NY	\$351	\$1,569	\$1,398	\$290	\$73	w	\$187
NC	\$234	\$1,454	\$1,666	\$299	\$37	w	\$48
ND	w	w	\$25	w	w	w	w
OH	\$218	\$1,608	\$1,494	\$651	\$1,029	\$100	\$1,647
OK	w	\$120	\$233	\$49	\$39	\$79	\$51
OR	\$70	\$97	\$1,686	w	\$119	w	\$48
PA	\$396	\$1,219	\$1,775	\$568	\$386	\$201	\$1,635
RI	\$87	\$73	\$69	w	w	w	\$35
SC	\$89	\$1,626	\$826	w	\$25	w	\$116
SD	w	w	\$44	w	w	w	w
TN	\$183	\$1,364	\$1,004	\$79	\$230	w	\$85
TX	\$371	\$3,706	\$1,541	\$244	\$284	\$1,054	\$265
UT	\$32	\$106	\$144	w	w	w	w
VT	w	w	\$132	w	w	w	w
VA	\$82	\$804	\$1,023	\$72	\$112	w	w
WA	\$326	\$213	\$1,540	\$29	\$62	\$92	w
WV	\$107	\$634	\$159	\$104	w	w	\$345
WI	\$49	\$402	\$2,363	\$115	\$660	w	\$66
WY	w	\$47	\$30	w	w	w	w

Source: 1994 Annual Survey of Manufactures, Bureau of the Census

w = data withheld or not applicable

Bold figures indicate the 10 States with the largest payroll for each industry.

Table A-4. Estimated Contribution of Materials and Process Industries to Economic Output of States, 1992

	Aluminum	Chemical	Forest Products	Glass	Metal Casting	Petroleum Refining	Steel
AL	0.81%	3.12%	5.55%	0.09%	0.59%	w	0.97%
AK	w	w	0.98%	w	w	w	w
AZ	0.68%	0.94%	0.68%	0.05%	0.03%	w	w
AR	0.51%	1.59%	5.95%	0.10%	0.21%	w	0.83%
CA	0.05%	1.21%	0.76%	0.18%	0.07%	0.42%	0.06%
CO	w	0.36%	2.26%	0.05%	0.02%	w	0.12%
CT	0.38%	2.53%	0.93%	0.06%	0.01%	w	0.06%
DE	w	6.68%	1.62%	w	w	w	0.18%
DC	w	w	w	w	w	w	w
FL	0.03%	1.03%	0.80%	0.10%	0.01%	w	0.04%
GA	0.47%	2.11%	3.45%	0.37%	0.09%	w	0.07
HI	w	0.12%	0.06%	w	w	w	w
ID	w	2.76%	3.53%	w	w	w	w
IL	0.27%	3.13%	1.06%	0.21%	0.22%	0.34%	0.55%
IN	1.01%	5.19%	1.69%	0.52%	0.66%	w	3.51%
IA	w	3.50%	1.38%	w	0.29%	w	w
KS	w	1.74%	1.08%	0.38%	0.15%	0.76%	w
KY	0.86%	3.36%	1.59%	0.47%	0.23%	w	0.74%
LA	0.04%	7.85%	2.67%	0.08%	0.03%	2.64%	0.09%
ME	w	0.62%	8.19%	w	w	w	w
MD	w	1.91%	0.67%	0.02%	w	w	w
MA	0.20%	1.30%	0.96%	0.21%	0.02%	w	0.05
MI	0.14%	3.18%	1.36%	0.31%	0.55%	w	0.55%
MN	w	0.89%	2.62%	w	0.21%	w	0.09%
MS	0.44%	2.91%	5.07%	0.29%	0.05%	w	0.14%
MO	0.27%	4.25%	1.54%	0.14%	0.21%	w	0.21%
MT	w	0.38%	2.89%	w	w	w	w
NE	w	1.51%	0.45%	w	0.05%	w	w
NV	w	0.38%	0.18%	w	w	w	w
NH	0.75%	0.54%	2.40%	0.09%	0.42%	w	0.04%
NJ	0.17%	6.95%	0.77%	0.30%	0.07%	0.13%	0.10%
NM	w	0.21%	0.31%	0.07%	w	0.38%	w
NY	0.19%	1.53%	0.57%	0.17%	0.03%	w	0.11%
NC	0.35%	5.99%	2.13%	0.61%	0.04%	w	0.05%
ND	w	w	0.29%	w	w	w	w
OH	0.23%	3.38%	1.48%	0.75%	0.66%	0.15%	1.85%
OK	0.09%	1.14%	1.16%	0.41%	0.12%	0.61%	0.21%
OR	0.51%	0.51%	6.88%	0.17%	0.51%	w	0.17%
PA	0.31%	3.25%	1.81%	0.62%	0.26%	0.58%	1.29%
RI	0.99%	0.72%	0.68%	0.10%	0.07%	w	0.29%
SC	0.14%	8.81%	3.79%	0.27%	0.10%	w	0.25%
SD	w	0.22%	0.94%	w	w	w	w
TN	0.62%	4.90%	2.26%	0.19%	0.28%	w	0.22%
TX	0.18%	4.41%	0.76%	0.18%	0.11%	1.02%	0.15%
UT	0.28%	1.00%	0.76%	0.07%	0.14%	0.94%	w
VT	0.43%	0.39%	3.25%	0.16%	w	w	w
VA	0.12%	2.77%	1.68%	0.12%	0.16%	w	0.05%
WA	0.73%	1.48%	2.90%	0.06%	0.09%	0.20%	0.05%
WV	0.71%	9.10%	1.12%	1.02%	0.10%	w	2.10%
WI	0.11%	1.73%	5.80%	0.34%	0.95%	w	0.12%
WY	w	2.73%	0.47%	w	w	0.78%	w

Sources: 1994 Annual Survey of Manufactures, Bureau of the Census; Bureau of Economic Analysis
w = data withheld or not applicable

Bold figures indicate the 10 States with the highest percentage of state product for each industry.

METHODOLOGY FOR CALCULATING POTENTIAL BENEFITS OF OIT-SUPPORTED TECHNOLOGIES

To evaluate the potential benefits of OIT-supported technologies, a market analysis was conducted for many of the projects described in this report. The following discussion describes the procedures used to conduct the market analysis, the model methodology, and how potential benefits were derived.

Conducting the Market Analysis

The first and most critical step in conducting the market analysis is the collection of credible technical and market data. Data were collected from OIT program managers, principal investigators, and technical reports and literature. Information was assimilated in each of the following categories for both the OIT technology and the principal competing technology (if applicable):

- Capital costs (installed)
- Annual nonenergy operating costs (e.g., raw materials, operating and maintenance supplies, labor, pollution control expenses, transportation)
- Annual energy use
- Annual waste generation (e.g., solid waste, toxic waste, wastewater)

Data were collected on a unit basis (e.g., values for a single operating unit of a selected size and operating capacity). For the OIT technology, data were also obtained on the expected penetration of the technology into the marketplace, including

- Year of introduction of the technology to the marketplace
- Number of units of technology in place during the year of introduction
- Expected maximum target market for the technology
- Maximum penetration of the technology into the target market (percentage of market share)

The above data were then input to the model to predict the benefits of each technology over the next 30 years.

How the Model Works

The *OIT Project Benefit Analysis Worksheet* is a system of Microsoft Excel spreadsheets developed to aid in the financial, market, and benefits analysis of OIT's industrial R&D projects. After the analyst enters data as described above, the model then calculates a number of statistics based on the investment in new technology as compared to an assumed next-best investment in the existing technology. These statistics include initial capital investment, total annual costs, and standard pretax, constant-dollar financial measures (e.g., internal rate of return, payback). These statistics are then used to calculate the market penetration of the technology over the next 30 years.

The market penetration model incorporated in the spreadsheet system is a modified Mansfield-Blackman model. The market penetration model is driven by the ratio of the internal rate of return (IRR) for the marginal investment in the new technology to a "hurdle rate" set by the analyst (25% for the current portfolio analysis). The market projection is also influenced by the size of the capital investment involved and the number of new units assumed to be installed at the point of market introduction. Once the size of the market has been predicted, the model then estimates the benefits that will accrue as the technology is adopted.

Benefits

Energy savings, production cost savings, and reductions in emissions and waste are calculated by the model for each unit, based on a comparison between the OIT technology and the principal competing conventional technology. Once market penetration of the OIT technology has been predicted, the model calculates total benefits for the technology by multiplying the unit savings by the number of units expected to be in place in any particular year. For example, if 1 unit of a particular technology is expected to save 1 billion Btu of natural gas/year and 40 units are projected to be in place by 2025, then total energy savings for 2025 would be 40 billion Btu.

Energy savings include energy used during processing as well as the embodied energy in feedstocks and raw materials. Production cost savings include the cost of energy saved as well as other manufacturing cost savings due to the increased efficiency of the OIT technology (e.g., less maintenance, lower labor requirements, reductions in raw material use, and so on). Reductions in fuel combustion-related air emissions are calculated by the model using published conversion factors for fossil fuel combustion and are based entirely on fossil energy fuel savings. Waste reduction includes solid wastes (hazardous, non-hazardous, and toxic) as well as any other liquid or gaseous effluents that are not combustion related, and are based strictly on the input data provided.

Model Uncertainties

The model results provided in this report illustrate the potentially large energy, economic, and environmental benefits achievable from the implementation of more advanced, energy-efficient, and cleaner manufacturing technologies. However, the limitations of modeling must be considered when attempting to predict what will happen 20 to 30 years in the future. Many unexpected events will occur during that time in the marketplace as well as in technology development. With this in mind, the benefits of OIT's R&D portfolio are quite valid within the range of uncertainty that the future holds.

METHODOLOGY FOR CALCULATING EMPLOYMENT IMPACTS OF OIT-SUPPORTED TECHNOLOGIES

Employment Impacts Derived from an Input-Output Model

Employment impacts of the adoption of OIT technologies are estimated by inserting annualized costs and benefits of the technology into a model of the economy as depicted in the benchmark input-output (I/O) table of the U.S. economy for 1987, published by the U.S. Department of Commerce.

The annualized benefits (costs) are subtracted from (added to) the purchases of commodities by the adopting industry as represented in the use matrix. This represents a net resource savings that is attributed to an increase in value added and hence must be added to the final demand vector. This modified use matrix is then used to construct a modified direct and indirect requirements matrix, which with the modified final demands, is used to calculate industry output. These outputs are then multiplied by the employment intensities for each industry and summed to determine how employment changes as the technology is put to use. This calculation is repeated annually as the technology penetrates into the market, providing a picture of how the impacts will change with the adoption of the technology. The base period is always the employment that would have occurred absent the technical changes to the use matrix. This is equivalent to translating net benefits of the technology adoption expressed in dollars of GDP into employment units.

Assumptions

Fundamental to the estimation of the employment impacts of the adoption of OIT technologies is the assumption that any technological improvement will improve efficiency. The adoption of the technology will free resources that, when put to work at alternative uses, will allow greater output with the same set of inputs. The process by which this actually occurs is a complicated one, not well treated in the economics or technology innovation literature.¹

Because of these complications, some simplifying assumptions have been made that make the problem more tractable. The first of these is that the costs and benefits of the technology are

annualized, so that there is no concern about the timing and financing of the investment that embodies the technology. As a result of this assumption, the only dynamic impacts are the result of market penetration of the technology over time. A second assumption is that the resource savings, represented by the reduction in costs to the industry adopting the technology, instantly is translated into increases in final demand. How this transfer occurs is not addressed in this model.

The Methodology Illustrated

A simple example explains how this calculation is performed. Consider an economy with only two sectors: farmers and miners. Ten miners supply coal for the entire economy; they produce 1 ton of coal per person per year. Ninety farmers produce 900 bushels of grain per year (10 bushels per person). The simple representation of the economy is shown in Table A-5. Each of the hundred people in the economy requires 9 bushels of grain and 200 pounds of coal to provide a "normal" standard of living. Thus the mining sector consumes (purchases) 90 bushels of grain and 1 ton of coal while the farming sector purchases 810 bushels of grain and 9 tons of coal.

Suppose an energy conservation innovation occurs that improves the efficiency of coal use so that, where 200 pounds were formerly needed, now only 180 pounds are needed (i.e., an efficiency improvement of 10%). Further assume that only farmers adopt this new technology instantly. Initially, the economy produces a surplus of 0.9 ton of coal, or, in employment terms, the benefit of this innovation is slightly less than one miner, since each miner produces 1 ton of coal.

With the economy somewhat out of adjustment, let us further suppose that over an unspecified period of time two things occur. Miners see the advantage of adopting the technology and one miner decides to abandon mining in favor of the more bucolic agricultural life. After adjustments, the economy is as shown in Table A-6. Now the economy produces 910 bushels of grain and 9 tons of coal. Miners consume 0.81 ton of coal and 81 bushels of grain, and farmers purchase 8.19 tons of coal and 819 bushels of grain. Total consumption, then, is 900 bushels of

Table A-5. Initial Conditions: Farmers and Miners

		Purchases by:		Total
	Total Production	Farmers	Miners	Sales
Grain	900 (bushels)	810	90	900
Coal	10 (tons)	9	1	10

METHODOLOGY FOR CALCULATING EMPLOYMENT IMPACTS OF OIT-SUPPORTED TECHNOLOGIES

Table A-6. New Equilibrium: Occupational Shift

		Purchases by:	Purchases by:	Total
	Total Production	Farmers	Miners	Sales
Grain	910 (bushels)	819	81	900
Coal	9 (tons)	8.19	0.81	9

grain and 9 tons of coal, yielding a surplus of 10 bushels of grain. This surplus, in employment terms, is equivalent to one farmer. So after the economy has adjusted, the employment equivalent of the surplus in one additional farmer (or one miner, since the miners have adopted the new innovation also). It is in this sense that the employment estimates associated with OIT technology adoption should be interpreted.

Issues

There are a number of issues that this approach does not address that need to be identified, though not resolved. An I/O representation of the economy is a static concept — it is a snapshot at a particular point in time. Using a static model neither allows any consideration of the adjustment process, nor does it take into account how the investment might be financed, nor does it consider adjustments that might occur in the labor and other goods markets as a result of freeing resources from the industry making the innovation. The treatment by Carter (1990) shows that when resources are fully employed after the technological change, output may be larger, but there is nothing intrinsic to the I/O approach that would assure that these resources are put back to work. The approach taken here assumes that the resource saving is instantly translated into greater final demand (i.e., higher GDP) just as the resource saving in the example above can be translated into an equivalent employment change.

This assumption ignores the fact that a “benefit” to one industry in the form of lower costs is a decline in sales (i.e., a “cost”) to another industry. As such, the value-added increase in the innovating industry should be precisely offset by a decrease in other industries. By ignoring these other industry impacts, we are supposing a lengthy chain of events that might first show up as lower costs, and that these costs would wash throughout the economy, allowing all industries to make marginal adjustments to the mix of labor, capital and materials that would, after adjustments, yield greater real output fully utilizing the available set of resources. If there are unemployed resources, these might be brought into productive use through these impacts.

Unfortunately, a static tool like I/O analysis does not fully allow for this type of adjustment. Hence the simplifying assumptions.

References

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Endnote

1. The only systematic treatments of this issue are by Henry (1977), who focuses on energy conservation changes, and Carter (1990), who codifies the impacts of various technical innovations in a static I/O framework. The consequence of technology change in a dynamic context may be addressable using a model such as the one presented by Persson (1984), although this model assumes full employment of resources also. For there to be positive employment impacts, there must be an elastic labor supply response function. See Scott et al. for financing implications.