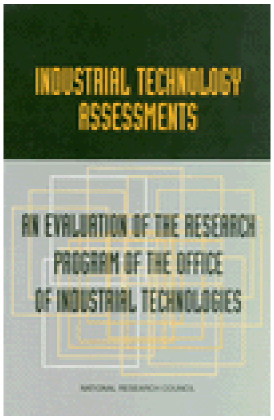

Industrial Technology Assessments: An Evaluation of the Research Program of the Office of Industrial Technologies

Committee on Industrial Technology Assessments, Commission on Engineering and Technical Systems, National Research Council

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INDUSTRIAL TECHNOLOGY ASSESSMENTS

An Evaluation of the Research Program of the Office of Industrial Technologies

Committee on Industrial Technology Assessments

National Materials Advisory Board
Board on Manufacturing and Engineering Design
Commission on Engineering and Technical Systems

National Research Council

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This report has been reviewed by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the authors and the NRC in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The content of the review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report: James

J. Solberg, Purdue University; Edward Dowling, Cleveland Cliffs, Inc.; Gordon Forward, TXI Corporation; Michael Thomas, Alcan Aluminum Corporation; and Jay Lee, United Technologies Research Center.

While the individuals listed above have provided many constructive comments and suggestions, responsibility for the final content of the report rests solely with the authoring committee and the NRC.

Finally, the panel gratefully acknowledges the support of the staff of the National Materials Advisory Board and Board on Manufacturing and Engineering Design, including Thomas E. Munns, study director, and Aida C. Neel, senior project assistant.

Preface

In 1993, the U.S. Department of Energy (DOE) Office of Industrial Technology (OIT) established a group of seven industries designated as Industries of the Future (IOF). These industries were selected for their high energy use and large waste generation. The original IOF included the aluminum, chemicals, forest products, glass, metalcasting, petroleum refining, and steel industries. Each industry was asked to provide a future vision and a road map detailing the research required to realize its vision. In November 1994, the forest products industry was the first of the IOF industries to enter into an agreement with DOE.

OIT asked the National Research Council's National Materials Advisory Board (NMAB) to provide guidance for OIT's transition to the new IOF strategy. The Committee on Industrial Technology Assessment (CITA) was formed for this purpose with the specific tasks of reviewing and evaluating the overall OIT program, reviewing selected OIT-sponsored research projects, and identifying crosscutting technologies (i.e., technologies applicable to more than one industry). CITA was asked to focus on three specific areas: intermetallic alloys, manufacturing process controls, and separations. A separate panel was formed to study each area and publish the results in separate reports.

The committee was composed of experts with a wealth of knowledge in industrial processing, industrial energy utilization, and environmental issues and technologies. The committee members, in addition to serving on panels, held four meetings to develop the overall program assessment and to oversee the study panels. The committee meetings included briefing sessions on the organization and status of the OIT program; a review of project selection and management issues in industrial, academic, and government research programs; a review of specific IOF industry approaches to project selection and prioritization; and a discussion of the role of the national laboratories in the IOF program. The conclusions and recommendations of the committee can be found in chapters 3 and 4. Chapter 3 includes general conclusions and lessons to be drawn from the panel studies of selected crosscutting technologies. Chapter 4 includes the committee's assessment of the overall program.

The chair wishes to thank the committee members for their enthusiasm, dedication, and service and the excellent OIT staff for their assistance, cooperation, and professionalism. The chair thanks all of the participants for their insights and stimulating discussions and the staff of the NMAB for their coordination and assistance throughout the entire process, including the publication of this report.

Comments and suggestions can be sent via electronic mail to nmab@nas.edu or by FAX to NMAB (202) 334-3718.

R. RAY BEEBE, *chair*
Committee on Industrial
Technology Assessments

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Acronyms

AF&PA	American Forest and Paper Association
AIM	advanced industrial materials
AISI	American Iron and Steel Institute
API	American Petroleum Institute
ATS	advanced turbine systems
CEO	chief executive officer
CFCC	continuous-fiber ceramic composites
CITA	Committee on Industrial Technology Assessments
CMC	Cast Metals Coalition
CTO	chief technology officer
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
DOE	Department of Energy
ECUT	energy conversion and utilization
FY	fiscal year
I&I	Inventions and Innovations
IOF	Industries of the Future
LCC	Laboratory Coordinating Council
MEMS	microelectromechanical systems
$NICE^3$	National Industrial Competitiveness through Energy, Environment, and Economics
NMA	National Mining Association
NRC	National Research Council
NSF	National Science Foundation
OIT	Office of Industrial Technology
ORNL	Oak Ridge National Laboratory
R&D	research and development

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Executive Summary

Since it was established in 1977, the Office of Industrial Technology (OIT) of the U.S. Department of Energy (DOE) has played a key role in providing federal support for industrial research and development (R&D). Recently, OIT undertook a transition to a new strategy, the Industries of the Future (IOF) Program, which identified a number of energy-intensive industries whose R&D goals could help OIT leverage the limited funds available from government and private sources. The IOF program commenced in 1994 with the establishment of the Forest Products Industry Group. Subsequently, industry groups were established for the agriculture, aluminum, chemicals, glass, metalcasting, mining, petroleum refining, and steel industries.

The objective of OIT's research programs is to work with U.S. industry to improve energy efficiency, reduce waste, and increase productivity. The IOF strategy is intended to improve OIT-industry partnerships, ensure the relevance of research projects, encourage industry participation, and facilitate the commercialization of developed technologies. According to OIT's strategic plan, the long-term goals are a 25 percent improvement in energy efficiency and 30 percent reduction in emissions for the IOF industries by 2010 and a 35 percent improvement in energy efficiency and 50 percent reduction in emissions by 2020.

The objectives of the present study were (1) to evaluate the overall OIT program strategy, (2) to provide guidance during the transition to the new "market-pull" IOF strategy, and (3) to assess the effects of the new strategy on crosscutting technology programs, that is, programs to develop technologies applicable to several industries.

RESEARCH PROJECTS

The IOF strategy was intended to improve the government-industry partnerships in OIT's research program, ensure the relevance of the research portfolio, encourage industry participation, and facilitate the commercialization of developed technologies. To implement the strategy, OIT (1) facilitated the development of industry visions and technology road maps, (2) initiated cooperatively funded R&D projects identified in the visions and road maps to develop enabling technology and reduce barriers to implementation, (3) sponsored generic (or crosscutting) R&D projects, and (4) disseminated research results and program benefits.

The OIT program has three primary parts:

- *IOF-specific programs* to prioritize and focus OIT research on identified needs based on industry-developed visions and technology road maps.
- *Crosscutting technology programs* to conduct research projects applicable to more than one industry.
- *Technology access programs* to provide industry with information and technical assistance, and to assist with technology transfer and technology demonstrations.

IOF-Specific Programs

Allocation of Support

Growing support for IOF-specific research reflects the industry groups' progress in developing visions and road maps to establish research priorities. Now that most of the industry groups have developed at least preliminary road maps, the committee recommends that OIT establish a rational, transparent process for allocating funds among IOF industries and allow the IOF industries to establish specific project directives (provided that the projects are consistent with OIT's mission). During the allocation process, OIT should assess the technical needs and priorities of each IOF group and consider several factors, such as the size of the industrial community, the potential effect of the research on OIT goals, the ability of the industry to support implementation, and other potential sources of support.

OIT has continued to expand the number of IOF industries. The agriculture industry was added in 1997 and the mining industry in 1998. The committee believes that increasing the number of industry groups can be effective as long as the new industries meet the initial criteria as large users of energy and producers of industrial waste. The committee recommends that OIT continue to apply the established metrics of energy consumption and waste generation in selecting industries for participation in the IOF program.

In the committee's opinion, the IOF program has been a success so far, principally in facilitating the creation of industry visions and technology road maps. Although the committee believes that the IOF strategy will make the OIT program more effective, the effect in terms of OIT's mission of reducing waste and energy consumption cannot yet be assessed. The committee recommends that OIT adhere to the IOF philosophy (i.e., working closely with industry and allowing industry to guide the process and set priorities). The committee also recommends that OIT take the following steps to maintain the positive momentum of the program:

- Continue to provide significant funding for research to address identified industry needs
- Utilize IOF industry representatives to monitor ongoing projects and evaluate planned projects (both IOF-specific projects and crosscutting projects)

Finally, the committee recommends that OIT perform a "portfolio analysis" to evaluate the overall research program. The analysis should include technical risk, potential payoff (in terms of energy savings and waste reduction), and time frame (near-term or long-term). The overall portfolio balance should be considered in the evaluation, as well as the prioritization of research projects; projects should be added or trimmed to balance the portfolio, as necessary.

Crosscutting Programs

One purpose of this report is to determine how well OIT identifies, prioritizes, and manages crosscutting technology initiatives. Current initiatives include advanced turbine systems, advanced industrial materials, continuous fiber ceramic composites, and sensors and controls. To facilitate its assessment, the committee established three topical panels to review different types of crosscutting technology initiatives. The panels studied OIT's Intermetallic Alloy Development Program (a component of a mature program already focused on crosscutting R&D), manufacturing process controls (identified in several industry visions as critical to their competitiveness), and industrial separations technologies (identified in several industry visions as enabling technologies). Each panel produced a peer-reviewed report that included specific technological recommendations and provided a case study for the committee's overall program assessment.

OIT's current program has two types of crosscutting research: (1) existing projects that predate the IOF strategy that have been relabeled as crosscutting projects and (2) projects of significant interest to several IOF industries that could be more efficiently managed and leveraged if they were merged into a crosscutting program. The committee believes that only the latter are consistent with the IOF strategy and recommends that OIT complete its transition to the IOF strategy by shifting the balance of IOF-specific and crosscutting research to emphasize industry-specific research identified on industry road maps.

Crosscutting programs that predate the IOF strategy include major initiatives, such as the Advanced Turbine Systems Program (ATS), the Continuous-Fiber Ceramic Composite (CFCC) Program, and the Advanced Industrial Materials (AIM) Program. Although the committee did not evaluate these programs in detail, they do not necessarily fit in with the IOF philosophy because they were not developed in response to the vision and road map processes. The committee recommends that these initiatives be either (1) managed separately from the IOF-specific projects or (2) re-evaluated and brought within the IOF framework.

The committee recognizes that relying on a market-pull strategy to define R&D objectives has inherent drawbacks. Crosscutting research opportunities are often related either to (1) embryonic technologies that have the potential for enabling major advances in multiple industries or (2) more mature, high-use technologies where incremental improvements could have a substantial effect. A key challenge for OIT is to manage crosscutting programs within the IOF framework in a way that will facilitate the development of specific R&D performance goals based on the common needs of several industries. Although there is no simple, self-reinforcing mechanism for identifying promising programs, the committee recommends that OIT follow the approach outlined below to manage crosscutting programs:

- Develop a consensus among the IOF industries that a certain percentage of R&D funds should be allocated for basic science and the development of crosscutting technologies.
- Using established management procedures, define and select a recommended list of basic/crosscutting technologies for development.
- Review these recommendations with the IOF industry groups and solicit their support and feedback.
- Collaborate with other DOE offices, including Basic Energy Sciences, other applied program offices, and relevant national laboratories, in crosscutting research projects.
- Establish a coordination group in each crosscutting technology area to develop short-term and long-term goals and to monitor the progress and results of research.
- Facilitate communication between researchers and potential IOF users (e.g., technical progress reviews and technology workshops).

Finally, OIT should adopt metrics compatible with DOE's and OIT's organizational objectives for comparing and selecting crosscutting programs for the IOF program. These metrics should include (1) their potential for reducing the consumption of energy and raw materials and for reducing the generation of waste, (2) their consistency with the technology road maps of the IOF industries, (3) their commercial potential/market value, and (4) their potential for use in more than one industrial sector.

Technology Transfer

Commercialization

As part of the change to the IOF strategy, OIT made a commitment to increase and document the commercial impact of its programs. Changing from a "technology-push" strategy to a market-pull strategy requires responsiveness and good channels of communication between OIT and industrial participants. For example, the recommendations in the previous section to involve IOF industries in the management of basic research and crosscutting technology development programs would facilitate technology transfer. However, technology transfer does not necessarily ensure successful commercialization. The commercialization of a new technology is a difficult and risky proposition even for corporations that specialize in, and depend upon, this commercialization.

In some ways, it might be inappropriate for a government program to measure the success of its R&D by technology transfer and commercialization. Because it has no profit motive or profit-making capabilities, OIT or any other government agency cannot fully participate in the commercialization process. A third party must commercialize the technologies developed by OIT, and the committee recommends that OIT only participate directly in commercial insertion programs for the purpose of identifying additional technical hurdles.

Although OIT should not participate in the final phases of the commercialization process, the committee believes that the following actions would facilitate commercialization:

- Maintain regular interactions with all critical stakeholders in the supply chain through all stages of program development, including raw material suppliers, parts makers, and systems integrators.
- Publicize the technical accomplishments of the program at popular trade meetings (e.g., the Society of Automotive Engineers, the Society of Plastics Engineers, ASM International, and the American Chemical Society). Use these meetings as an opportunity to meet and network with technical and business people.
- Establish networks that include not just technical people, but also sales, marketing, and senior management personnel.
- Expose technical personnel to basic business principles, including elements of cost estimation, value analysis, and market research. Insist that rudimentary business plans accompany each later-stage R&D program and have these plans critically reviewed by the industry stakeholders.
- Subsidize and participate with third-party practitioners of the technology in selected programs to demonstrate and de-bug the technology. These activities should not be confused with actual commercialization and should be limited to technologies that require additional technical devel-

opment. The government should not be the only supporter of ongoing insertion programs.
- Recognize that technology development is only one very small link, albeit an important one, in the commercialization process.

Technology Access Programs

OIT has a number of technology access programs designed to validate and commercialize new energy-saving manufacturing technologies. These include open competition grant programs, including the National Industrial Competitiveness through Energy, Environment, and Economics (NICE[3]) and the Inventions and Innovation (I&I) programs. Other programs are aimed at particular energy and environmental goals, including Motor Challenge, Climate Wise, and Industrial Assessment Centers. Although technology access programs can provide valuable assistance to businesses attempting to validate and implement industrial technologies that reduce energy use and waste generation, these programs predate the IOF strategy and do not correlate well with IOF road maps and priorities. The committee recommends that OIT establish technology access programs that are driven by IOF road map validation and commercialization plans established and planned from the onset of OIT participation.

PROGRAM MANAGEMENT

Role of Industry Groups in Managing Projects

Each industry has developed processes to include the IOF industry groups in the management of industry-specific projects, including the development of solicitations based on industry road maps; the assessment and prioritization of proposed research; and, in some cases, the assessment of progress and dissemination of results. However, it will be difficult to manage crosscutting initiatives within the IOF framework in a way that facilitates the establishment of performance goals based on the common needs of several industries. The committee recommends that industry play a substantial role in the management of the entire OIT research portfolio, including IOF-specific and crosscutting programs.

Communications

OIT has a number of mechanisms for communicating the status and accomplishments of research programs, including technology workshops; technical publications; a detailed information site on the Worldwide Web; a biannual Industrial Energy Efficiency Symposium and Exposition; and the promotion of project solicitations in *Commerce Business Daily*, through the Worldwide Web, and through the industry associations involved in the IOF program. Nevertheless, the committee believes that the overall OIT program (including the IOF) could be promoted more effectively. In many cases, OIT is the only significant government sponsor of research focused on process industries. Broader promotion of current opportunities and wider dissemination of research results and accomplishments would encourage more industry participation in the program. The committee recommends that OIT promote the program in the following ways:

- Describe technical successes in the trade literature, at technical society and industry trade meetings, in the popular press, and through other high visibility communications media.
- Promote industry participation in programs to validate and implement technologies.
- Describe the program approach, objectives, and level of participation at high-level symposia or forums hosted by the secretary of energy to maintain the interest of industry executives in the program.

Metrics

There are many approaches to measuring the efficacy of R&D. Each method has proponents and detractors, and none is universally or even widely accepted. The committee recommends that OIT consider the following metrics as a basis for comparing and selecting projects to support:

- potential for energy conservation
- cost/benefit ratio (i.e., risk-adjusted return on investment)
- consistency with IOF business objectives and technology road maps
- commercial potential/market value
- potential for use by more than one industrial sector (crosscutting potential)

The best metrics for measuring the efficacy of OIT research programs are likely to be some of the same measures used by the IOF industries internally. R&D managers from these industries should be contacted and polled regarding their approaches to setting priorities and measuring effectiveness. However, OIT should keep in mind that the "profit-based" metrics used by some industries may not be appropriate for assessing government-funded research.

Program Turnover

The success of the OIT program will continue to be measured by the level of industry participation. The implementation of new technologies and periodic reevaluations of the research agenda in response to changing industry priorities will be essential to maintaining industry support. The committee believes that the experience of mid-sized to large-sized enterprises that have a mix of technology development and product development could be used to guide OIT's management of project turnover. Industrial research and product development are typically based on four-year to five-year commitments (i.e., 20 to 25 percent of projects turn over each year). The committee recommends that, as part of the overall project management process, OIT develop a mechanism for the orderly termination of (1) projects that have met OIT objectives and have progressed to the market introduction stage of commercialization and (2) projects that do not have sufficient industrial interest to support demonstration, process development, and scale-up.

1

Introduction

The U.S. Department of Energy (DOE) Office of Industrial Technology (OIT) sponsors research and development (R&D) to improve energy efficiency, resource utilization, and the competitiveness of energy- and waste-intensive industries. The R&D projects are focused on the materials processing industries and are aimed at developing technologies that reduce the use of raw materials and energy, reduce the amount of waste generated, and increase industrial productivity. The OIT program has three primary components:

- Industries of the Future (IOF)-Specific Programs. Industry-developed visions and technology road maps are used to prioritize and focus OIT research on identified needs. Nine industries are currently participating in the program—agriculture, aluminum, chemicals, forest products, glass, metalcasting, mining, petroleum refining, and steel.
- Crosscutting Technology Programs. These R&D projects, which are applicable to more than one industry, are managed separately. Current crosscutting technology areas include advanced turbine systems, advanced industrial materials, continuous-fiber ceramic composites, and sensors and controls.
- Technology Access Programs. These programs provide information, technical assistance, technology transfer assistance, and technology demonstration assistance to industry. The object is to improve the productivity and energy/environmental performance of processing industries, other major industrial energy consumers, and small businesses.

Since 1993, OIT has been undergoing a transition from a "technology-push" strategy, in which research projects are selected and prioritized primarily for their potential to reduce energy consumption or waste generation, to a "market-pull" strategy, in which identified industry needs and priorities are used as the primary criteria. To pursue the new strategy, OIT has focused on energy- and waste-intensive materials processing industries. The original industries in the program were aluminum, chemicals, forest products, glass, metalcasting, steel, and petroleum refining. These industries, designated as "Industries of the Future" (IOF), use about 80 percent of the energy and generate more than 90 percent of the manufacturing waste in the U.S. industrial sector. Recently, agriculture (e.g., renewable bioproducts) and mining were added to the group.

Representatives of the selected industries developed technology "visions" that identify their high-priority needs, including their strategic goals and research priorities. Based on these visions, the industry groups have developed "road maps" (research agendas), devised implementation strategies to meet their high-priority needs, and committed resources to conduct and manage the research projects. OIT assisted with planning, facilitated interactions between participants, provided access to the DOE-administered national laboratories, and shared the costs of selected projects.

COMMITTEE ON INDUSTRIAL TECHNOLOGY ASSESSMENTS

In 1995, OIT requested that the National Research Council (NRC), through the National Materials Advisory Board, conduct a study to (1) evaluate their program strategy, (2) provide guidance during the transition to the market-pull IOF strategy, and (3) assess the effects of the new strategy on its crosscutting technology programs. The Committee on Industrial Technology Assessments (CITA) was established to complete the following tasks:

- review and evaluate the program and plans of the overall OIT program
- review the plans and progress of selected OIT-sponsored research programs
- conduct site visits and evaluate laboratories, when appropriate, to supplement program assessments
- suggest improvements to the technical programs, methods of coordinating research with other agencies, and mechanisms for transferring technology to industry

CITA established several panels to study specific aspects of the OIT technical program to help the committee with the overall program review. The committee used these panel studies on intermetallic alloy development, manufacturing process controls, and industrial separations as case studies to support its overall conclusions and recommendations. The panel studies were published separately in peer-reviewed reports (NRC, 1997; NRC, 1998; NRC, 1999).

Panel on Intermetallic Alloy Development

The first panel evaluated the intermetallic alloy development program at the Oak Ridge National Laboratory (ORNL)(NRC, 1997). This program was selected because it is already a mature program focused on crosscutting R&D. The emphasis of the report was on lessons that could be derived from the development of Ni_3Al alloys and processes, which have been the focus of the intermetallics research program at Oak Ridge. The report included a review and assessment of the program and recommendations for the future, as well as an assessment of implications for the entire OIT program and the transition to the IOF strategy.

Panel on Manufacturing Process Controls

The second panel established under CITA was the Panel on Manufacturing Process Controls. The objective of this panel was to identify opportunities for technology development that could improve process controls in the materials processing industries of the IOF and to recommend areas of emphasis for a sensors and controls initiative. This topic was selected because manufacturing process controls were identified in several industry visions as critical to their future competitiveness. The panel conducted two workshops. The first identified IOF industry needs for process controls and sensing technologies, as well as needs that are common to multiple industries. The second workshop identified opportunities for developing advanced sensing and control technologies to meet industry needs (NRC, 1998).

Panel on Industrial Separations

The Panel on Separation Technology for Industrial Recycling and Reuse was established to identify the technology developments needed in the separation processes of the IOF industries and to recommend areas of emphasis in the OIT research program. This topic was selected because industrial separations were identified in several industry visions as important enabling technologies. The panel conducted two working sessions. The first, which involved the participation of representatives of the IOF industry groups, identified separation technology needs and crosscutting needs. The second identified opportunities for developing separation processes to meet industry needs (NRC, 1999).

REPORT OBJECTIVES

This report summarizes the committee's overall assessment of the OIT transition to the IOF program strategy. Chapter 2 provides an overview of the IOF program, including OIT's motivation and strategic approach. Chapter 3 provides the committee's assessments of crosscutting research initiatives, including summaries of the panel studies and their implications. Finally, Chapter 4 contains the committee's assessment of the IOF strategy and implementation and presents recommendations for improving OIT's overall program.

2

IOF Program Overview

Since it was established in 1977, DOE's OIT (and its predecessor, the Office of Industrial Programs) has played a key role in providing federal support for industrial R&D. OIT programs traditionally had drawn on input from industry, the professional societies, and other interest groups to determine which areas of technology to pursue. However, many of the projects selected were influenced more by their technological attractiveness than the needs of industry. Although many OIT programs were quite useful, and all were consistent with OIT's fundamental interest in energy efficiency and waste reduction, the overall program lacked a unifying principle for relating R&D to goals with a broad technical scope and wide industry acceptance.

In similar circumstances, some federal agencies have made decisions based on their own technical judgments rather than consulting with their industrial customers. Fortunately, OIT developed an entirely new approach. In 1992, OIT undertook an initiative to identify important energy-intensive industries and to use their R&D goals to leverage the limited funds available from government and private sources. The IOF program began in 1994 when an industry group for the forest products industry was established (see Box 2-1). Although the primary focus of the IOF program was on energy efficiency, the member industries were also large generators of waste and pollutants. Thus, the overall goals of the IOF program where expanded to include reducing the consumption of nonrenewable resources.

With strong support from DOE, OIT approached seven industries, chemicals, petroleum refining, forest and paper products, steel, aluminum, metalcasting, and glass. OIT already recognized that energy-intensive and waste-intensive industries offered the best targets for significant improvements and the best

BOX 2-1

A Case History: The Forest Products Industry

The U.S. forest products industry employs 1.4 million people and produces products valued at more than $200 billion per year. Among the nation's top 10 manufacturing industries, it was the first Industry of the Future to develop a long range vision, *Agenda 2020: A Technology Vision and Research Agenda for America's Forest, Wood and Paper Industry* (AF&PA, 1994). The vision document was developed by a group of chief technology officers (CTOs) from U.S. pulp and paper companies and endorsed by a working group of chief executive officers (CEOs) for the American Forest and Paper Association. Mr. Robert C. Williams, then CEO of James River Corporation, representing the U.S. industry, signed a compact with DOE, represented by then Secretary of Energy, Hazel O'Leary, in November 1994.

This significant event, however, has a rather interesting history. In 1993, OIT conducted a workshop called the "Pulp and Paper Mill of the Future" that was focused on the pulp and paper industry. Representatives of academia, industry, and the DOE national laboratories were invited to attend to discuss the long-term strategic needs of the pulp and paper industry. The emphasis of the workshop was on defining and documenting the long-term needs of the industry and determining how DOE could interact with the industry to address these needs. Although the meeting was informative and provided opportunities for personnel from the national laboratories to become familiar with technology issues in the paper industry, industry representatives seemed to be only lukewarm toward the notion of an "industry research vision." In any case, the industry participants were acting as representatives of their companies and were not organized as a group that could speak for the industry as a whole. A draft report, prepared by DOE-OIT, "Paper Industry of the Future: Strategic Plan FY1994-1999" was submitted to industry representatives for review in October 1993.

In the spring of 1994, Secretary O'Leary attended the Executives Conference of the Institute of Paper Science and Technology, a graduate school and research center supported by, and serving, the U.S. pulp and paper industry. There she met with a number of CEOs and apparently delivered a challenge, "If you won't help us develop a vision, we will do it for you." Soon thereafter, a group of CTOs, under the auspices of American Forest and Paper Association, came together to develop the industry's vision.

The CTOs first took stock of the current forest, wood, and paper industry and then described the desired state of the industry 25 years into

continued on next page

BOX 2-1 Continued

the future. They divided their long-range technology vision and research agenda into six areas that would advance the entire industry and that were suitable for precompetitive and cooperative activities. The high-priority areas were: sustainable forest management; improved capital effectiveness; environmental performance; energy performance; sensors and controls; and recycling. Each area was relevant to all three industry segments—forestry, wood products, and pulp and paper products.

After the compact between the U.S. pulp and paper industry and DOE was signed, six working groups were formed (one for each area), and they, in turn, created subcommittees of representatives of industry and academia. These subcommittees independently began to develop long-range visions of the industry (in their area) and to generate lists of their technology needs. Several of the groups got off to a quick start on their high-priority research needs because of similar activities sponsored by the Technical Association of the Pulp and Paper Industry (TAPPI, 1992, 1996). Not all committees started at the same time, and some members were uncertain as to what was expected of them, especially because of immediate pressure from DOE to propose projects for possible funding. Eventually, however, each working group developed a vision for the industry and each developed and delivered a portfolio of "Research Pathways."

opportunities for leveraging government R&D funds. Large companies, which have significant R&D capabilities, had to be involved, but if only individual large companies were represented, OIT would not be able to attain a broad industry consensus. In sharp contrast to many federal R&D programs, the IOF program solicited broad industrial participation through industry associations rather than individual companies. In fact, some industries are represented in the program by two or more associations.

MOTIVATION

OIT's motivation to move ahead with the IOF program arose in part from earlier experiences with government-industry R&D partnerships. Although a number of interesting and worthwhile projects had been pursued over the years, integrating OIT's mission and industry priorities posed a continuing problem. In some cases, government engineers and managers used responses to proposal solicitations to choose projects, identify interested industry groups and to secure partial funding. Sometimes proposals came from academic and other outside sources, which frequently generated a "technology push" to pursue technically attractive, sometimes visionary, projects.

In other cases, industry groups had put forward proposals of their own. An example was the Steel Initiative, a major program originally championed by the American Iron and Steel Institute (AISI) intended to carry out research on methods of producing iron and steel without using coke. Because of the size (in terms of membership) and economic importance of AISI, the project received political recognition, leading Congress to enact the Steel and Aluminum Energy Conservation and Technology Competitiveness Act of 1988 (P.L. 100-680; 15 U.S.C. 5101 *et seq.*), generally referred to as the Metals Initiative.

Although many of OIT's industrial R&D programs prior to IOF were successful, the forms they had taken were not appropriate to the political climate of the 1990s. To continue to thrive, OIT had to carry out its mission in ways that would attract support, including funding, from major industry groups, without becoming (or being perceived as) a form of "corporate welfare." To do this, OIT had to accomplish two tasks: (1) to engage the interest and support of corporate leaders at the highest levels; and (2) to present a logical and workable structure to DOE, the Administration, and Congress that could effectively leverage federal R&D funds.

IOF PROGRAM STRATEGY

The IOF strategy was to develop working relationships, first with industry associations and, through them, with the CEOs and other high-ranking officers of the member companies. This highly innovative approach differs dramatically from the usual contacts between government technologists and their industry counterparts. The strategy was intended to encourage a sense of "ownership" of the program by industry leaders. Industry would lead and own the process, commit its own human and material resources to the R&D, and benefit from the technological advancements. The key to industry support was that the "necessary" R&D would be identified by industry itself.

OIT would act as a facilitator, responsible for bringing together producers, suppliers, customers, stakeholders, and outside experts; easing access to other government agencies with interests parallel to those of the IOF; coordinating participation by other government technical and scientific organizations; and participating in R&D through selective cost-sharing. The essential quality of OIT's role would be its constant readiness to assist without trying to micromanage IOF activities.

IOF PROCESS

Once an industry association and the CEOs have been bought into the IOF process, they prepare a "vision document" outlining the industry's desired future for approximately 25 years. Generally, the industry association takes the lead role, and in some industries more than one association was involved in creating the vision document. Industry CEOs provide broad guidance, reinforce the sense of industry ownership, and communicate their commitment to the IOF process to the trade association and their own companies. The CEOs empanel a committee of technical experts, backed by consultants and academic authorities, to discuss the vision and draft the document for their approval and the approval of the industry association.

When the vision document is complete, the industry and DOE sign a compact establishing a research partnership. The compact briefly sets forth a framework for joint R&D technology demonstration and addresses specific, as well as crosscutting, technology needs in the general areas of energy efficiency, recycling, and waste minimization. Individual companies, industry associations, government agencies, universities, and other research institutions, acting in collaboration can carry out the research. Significantly, the program is explicitly intended to benefit the industry as a whole. Some research collaborations already under way are reinforced, rather than replaced, by the IOF program.

The next step in the IOF process is for an industry to prepare a "technology road map," with OIT acting as a facilitator. Industries may develop more than one road map to encompass multiple technologies and products. In contrast to the vision document, which is intended to describe an industry's desired future, strategic objectives and goals, and major challenges and barriers as revealed by situation analysis, the road maps are expected to be comprehensive, setting a technology strategy with milestones leading to realization of the vision. The road maps specify technical requirements, assess existing technologies, evaluate barriers and options, set technology priorities and paths to be followed, and establish targets and major milestones on the way to their realization.

Vision documents typically take from one to three years to complete, but ideas for the road maps are usually formulated during the process. Road maps are usually prepared through industry workshops, with OIT participation and the assistance of professional workshop management groups, and drafts are submitted for industry comment and approval. Some industries require more than one workshop; others divide the task among teams. The implementation of the IOF strategy for each participating industry is detailed in Chapter 4.

Throughout the IOF process, OIT continues to evaluate other industries. If an industry meets the OIT criteria (energy use and waste generation) and is committed to the process, it may be included in IOF. In late 1996, an industry team was formed for the agriculture industry. In September 1997, the board of directors of the National Mining Association (NMA) voted to become part of IOF and to begin working on a vision document.

Once an IOF industry sets its research priorities, solicitations for research proposals based on those priorities are issued. The solicitation processes differ among the IOF groups. Regardless of the approach, however, OIT is responsible for the final funding determinations.

To this point, the IOF program appears to be carefully thought out and efficiently managed. As road maps are completed and the pace of solicitation increases, however, OIT's management workload will necessarily increase. Two new industries (agriculture and mining) have joined the program, and other industries are being considered. For the program to remain successful, OIT must (1) adhere to its criteria for including new industries, and (2) develop an outreach program to communicate IOF results to industry.

3

Crosscutting Programs

The emphasis of this study is on how OIT identifies, prioritizes, and manages crosscutting technology initiatives. Current crosscutting initiatives include advanced turbine systems, advanced industrial materials, continuous-fiber ceramic composites, and sensors and controls.

To aid the committee in its assessment of the overall OIT program, the committee provided oversight to three topical panels to assess different types of crosscutting technology initiatives. These included intermetallic alloy development, part of a mature program already focused on crosscutting R&D; manufacturing process controls, an area identified in several industry visions as critical to their future competitiveness; and industrial separations, which were identified in several industry visions as important enabling technologies. The panel studies provided specific technological recommendations and were used by the committee as case studies for the overall program assessment. The panels provided the committee with important insights into OIT's identification of research priorities and management of the research portfolio. The case studies are summarized in the following sections.

CASE STUDY 1: INTERMETALLIC ALLOY DEVELOPMENT

The intermetallic alloy development program at ORNL was selected for review by the first panel under CITA because it is a mature program already focused on crosscutting R&D. The Intermetallic Alloy Development Panel was established to review the progress and accomplishments of the program; to describe program management strategies, including selection criteria, commercialization plans, and industry involvement; to describe successful and unsuccessful efforts to develop commercial applications for intermetallic alloys; to suggest potential applications in the OIT target industries; and to recommend criteria for selecting and prioritizing future projects for R&D on intermetallic materials and processes. The emphasis of the panel's report was on lessons that could be derived from the development of Ni_3Al alloys and processes (the focus of the OIT intermetallic research program at ORNL). The panel's findings included a review and assessment of the intermetallic alloy development program and recommendations for the future focus of the program, as well as an assessment of the implications for the entire OIT program and the transition to the IOF strategy (NRC, 1997). The major recommendations are included in this summary.

Intermetallic compounds are a unique class of materials consisting of ordered alloy phases formed between two or more metallic elements where the different atomic species occupy specific sites in the crystal lattice. Intermetallic alloys with high aluminum content have been considered for use in demanding structural applications because of their inherent oxidation resistance and strength retention at high temperatures. However, they can be extremely brittle at ambient temperatures, are difficult to process, and are prone to environmental degradation.

The development program at ORNL described in this case study was undertaken to increase the understanding and improve the properties of intermetallic compounds so that they could be processed and used as structural materials in demanding, high-temperature environments in a number of industries. The program, which was begun in 1981, is one of the longest continuously funded materials development programs ever undertaken at ORNL. OIT, through the Energy Conversion and Utilization (ECUT) and Advanced Industrial Materials (AIM) programs, has provided roughly one-third of the funding to ORNL for the development and commercialization of intermetallic alloys.

Program Assessment

Overall, the ORNL intermetallic alloy development program has been successful in terms of the technical goals and objectives established by the program (i.e., to develop high-strength, ductile intermetallic alloys that can be processed and utilized for high-temperature structural applications). The program has been well managed, with effective integration of program elements—from basic research through production scale demonstrations—and good coordination of program goals and responsibilities among funding and research organizations.

Program Management

In the panel's judgment, the ORNL intermetallics program has been a successful science and technology development program for a number of reasons. These include consistent and continuous funding (since 1982); effective integration of basic and applied R&D by universities, other national laboratories, and industry; the flexibility to reorient and refocus research in response to promising results or identified needs; and the establishment of partnerships and collaborations with industry to identify industry needs and establish practical goals for technology development.

Technical Program

Since its inception, the ORNL intermetallic alloy development program has made significant technical advances—from basic exploratory research and characterization through process development and scaling. The early decision to focus on Ni_3Al alloys and to concentrate on optimizing alloy composition, characterizing material behavior, and developing production scale processing methods has been critical to the success of the program.

Technical accomplishments in the characterization and development of Ni_3Al alloy compositions are listed below:

- the identification of brittle grain boundary fracture mechanisms at ambient temperatures and the substantial loss of ductility at intermediate temperatures as major material deficits
- the determination of causes of brittle fracture at ambient temperatures (moisture-induced embrittlement) and loss of ductility at intermediate temperatures (dynamic oxygen-induced degradation)
- the improvement of ductility by microalloying with boron and chromium
- the improvement of elevated-temperature strength and processibility using standard alloying techniques, including solid solution strengthening, dispersion strengthening, and improving strength, weldability, and castability

In the panel's judgment, some of the most significant accomplishments of the intermetallic alloy research program have been in the development of manufacturing processes. Developments in this area are listed below:

- a production-volume melting process that maintains aluminum concentration while melting higher-temperature-melting constituents (Exo-melt process)
- methods and alloy modifications for low-cost casting processes
- materials (e.g., weld wire) and processes for making structural welds and weld repairs

Commercialization

The results of the successful use of Ni_3Al alloys in a variety of trial production applications, as well as recent commercial orders for furnace transfer rolls in steel mills and heat treat furnace fixtures, indicate that the commercial use of these alloys is likely to increase in the next several years. However, although Ni_3Al alloys have performed well in production scale trials, it is unclear at this time if commercial use will repay the research investment.

Criteria that should be considered in the full commercialization of a new material include the following:

- The availability of suitable alternative materials. To replace an established material with a new material, factors other than performance must be considered, including the cost and supply of raw materials; production capability; cost of materials, fabrication processes, tooling, and facilities; demonstrated reliability; and supplier infrastructure.
- Industrial participation. Successful commercialization requires a strong, committed industrial proponent who understands the real hurdles and motivation for industrial acceptance.
- Technology readiness. The technology, especially the processing technology, must be substantially developed prior to commercialization.

Even though the ORNL intermetallic program's commercialization strategy has included these criteria, ORNL ultimately depends on industry to commercialize new technologies.

Future Program Focus

Throughout the history of the ORNL intermetallic alloy development program, interaction with industrial participants has been critical to identifying needs and priorities. Interactions with industry have helped ORNL focus on optimizing alloy compositions and developing process technologies to meet industrial needs. In addition to the collaboration mechanisms previously used by ORNL (cooperative research and development agreements, cofunded research projects, license agreements), IOF industry "vision documents" and road maps would help identify industry needs and priorities that could be met through the use of intermetallic alloys. Examples of potential applications include expanding the use of Ni_3Al for hot metalworking (dies, fixtures, furnace components), developing nickel and iron aluminides for processing equipment used in high-temperature and corrosive environments in the chemical and petroleum refining industries, and using Ni_3Al in transfer and processing rolls for the steel and paper industries.

In addition to characterizing the physical and mechanical properties of Ni_3Al, the focus should be shifted to modeling of solidification (casting and welding) processes and to establishing production processing standards and methods of machining and welding nickel aluminide and iron aluminide. This shift could extend the industrial applications and improve the potential for the commercialization of intermetallic alloys.

The panel believes that relying on industry needs alone, even with an effective identification strategy, has inherent drawbacks. For example, important crosscutting or exploratory research programs might not be supported if they are not identified as high-priority industry needs by any one group. Therefore, the panel made the following recommendations (NRC, 1997):

- ORNL should focus research on optimizing alloys and developing process technologies for a select number of alloy families for which ORNL has unique expertise and capability, the Ni_3Al-based alloys and iron aluminides (Fe_3Al, FeAl).
- ORNL should continue to emphasize the development of manufacturing process technologies for selected alloys to maximize opportunities for commercialization and technology transfer to industry.
- ORNL should emphasize low-cost processes in the development and optimization of intermetallic alloys.
- OIT and the ORNL intermetallic alloy development program should use the following approach to identify and prioritize research programs:
  - Identify IOF needs and priorities that can be met through the application of intermetallic alloys.
  - Establish, with input from IOF teams interested in the commercial uses of intermetallic alloys, a target level of support for crosscutting R&D programs.
  - Identify projects with the potential to meet identified industry needs, and develop material and process technology goals based on these potential applications.
  - Emphasize crosscutting projects that could lead to commercial application in more than one industrial sector.

Implications for the Office of Industrial Technology Program

The lessons learned from the development of Ni_3Al alloys and processes could provide OIT with general guidelines for coordinating and managing several funding and research organizations and for establishing effective industrial collaborations. These guidelines could then be used in the implementation of the IOF strategy throughout the OIT program. The panel made the following recommendations concerning the implications for the overall OIT program (NRC, 1997):

- OIT should emphasize the early involvement of key industrial participants, including the suppliers, producers, and users of particular materials or process technologies. OIT should adopt collaboration mechanisms, such as cooperative research and development agreements, cofunded research programs, exchanges of personnel, and the use of laboratory user centers (e.g., the ORNL Metals Processing User Center).
- OIT should support joint projects with potential suppliers and users of a specific technology to demonstrate and debut the technology.
- When licensing technology developed by an OIT R&D program, OIT

should specify the relationship between the R&D program and the licensee's business strategy. OIT should not enter into exclusive licensing arrangements that rely on unrealistic technology development for commercialization (i.e., licensing too early) or that unnecessarily restrict or preclude the use of the technology by other industries.
- OIT should develop a mechanism for the orderly termination of (1) projects that have met OIT objectives and progressed to the final stage of commercialization (market introduction) and (2) projects that do not have sufficient industrial interest to support demonstration, process development, and scale-up.

CASE STUDY 2: MANUFACTURING PROCESS CONTROLS

Manufacturing process controls include all systems and software that exert control over production processes. Control systems include: process sensors, data processing equipment, actuators, networks to connect equipment, and algorithms to relate process variables to product attributes.

The Panel on Manufacturing Process Controls was established to identify key processes and needs for improved manufacturing control technology, especially the needs common to several IOF industries; identify specific research opportunities for addressing these common industry needs; suggest criteria for identifying and prioritizing R&D to improve manufacturing control technologies; and recommend means for implementing advances in control technologies.

Manufacturing Process Controls was selected as the second panel under CITA because process monitoring sensors and process control technologies were identified in several industry visions as important to their future competitiveness. The emphasis of the panel's report was on identifying common research needs and the issues involved in establishing new crosscutting technology development programs that address the needs of multiple industries. The panel's findings included a summary of the needs for sensors and controls of the individual IOF industry groups, as well as a discussion of research opportunities to meet these needs (NRC, 1998). The major recommendations are included below.

Key Processes and Control Technology Needs

The panel identified common industry needs for process sensing and manufacturing process controls based on key IOF process attributes, including (1) high processing volume and production rates, (2) large-batch or continuous processes, (3) commodity-grade products (low value per unit), (4) harsh processing environments,[1] and (5) serial processing sequences (i.e., the output of one process becomes the feedstock for the next).

[1] A harsh processing environment has one or more of the following characteristics: high processing temperature (with respect to sensor and control capabilities); steep thermal gradients; corrosivity; erosivity; high particle content; combustion; or high processing speeds.

Common needs for process sensing include the following:

- measurement of temperature profiles in harsh processing environments
- measurement of chemical composition/stoichiometry in harsh processing environments
- measurement of physical attributes at high line speeds and high temperatures
- monitoring of combustion processes

Common needs for process controls include the following:

- methodologies to enable in-situ-level process controls
- optimization at the plant or enterprise level
- open-architecture software tools
- adaptive control systems
- methods and diagnostic tools for the condition-based maintenance of process equipment

To address all of these needs, the panel suggested an OIT program that includes (1) a crosscutting R&D initiative to develop fundamental technologies that address common IOF needs, (2) industry-specific R&D to validate and implement advances in technology, and (3) an interagency government initiative to coordinate plans and research objectives.

Research Opportunities

The panel recommended that OIT establish a crosscutting R&D initiative to address the common needs of the IOF industries. Examples of specific research opportunities (not prioritized) are listed below:

- the development of sensor materials with significantly improved thermal and chemical resistance
- the compilation of a comprehensive database of candidate sensor material properties to accelerate the design and development cycle for the fabrication of new sensor systems
- the development of methods to measure temperatures accurately and reliably
- the development of low-cost, miniaturized, integrated analytical instruments that can directly and easily measure process chemistry for a wide range of process flow-streams and conditions, including harsh environments
- the application of new processing science for the fabrication and packaging of integrated sensor/data processing/actuation modules
- the development of measurement technologies for the rapid characterization and evaluation of physical properties for wide-sheet and web processes
- the application of wireless telecommunications technology to advanced wireless sensors

- the development of process control methodologies, including process measurements, intelligent control algorithms, and reliable process models, to enable the transition from environmental-level (energy transport) to in-situ-level (material behavior) controls
- the development of techniques and control architectures for using multiple, disparate process models in a cohesive and integrated way
- the development of technology for process optimization and the plant-wide integration of process controls
- the evaluation of open-architecture control systems for large-batch and continuous processes typical of IOF industries
- the development and implementation of machine learning and adaptive controls

Criteria for Identifying and Prioritizing Research and Development

The panel recommended that OIT focus its research on the development of process sensors and control technologies that address the needs of the IOF industries. In addition to the common needs, the organizational objectives of DOE and OIT—to reduce the consumption of raw materials and energy, to increase labor and capital productivity, and to reduce waste—must be considered. The panel recommended the following criteria as a basis for comparing and selecting technologies for the crosscutting program:

- the potential for reducing the consumption of energy and raw materials and for reducing waste
- consistency with the technology road maps of the IOF industries
- potential crosscutting benefits for more than one industrial sector
- the potential for commercial application

One of the key challenges for OIT is to manage the crosscutting program in a way that will facilitate the development of specific R&D performance goals based on the common needs of several industries. To identify and prioritize research that meets IOF's needs, the panel recommended that OIT take the following steps:

- Establish an IOF coordination group to develop short-term and long-term goals and to monitor the progress and results of work on crosscutting technologies. The group would review process attributes and control needs in each IOF industry and establish a consensus on specific goals for the most beneficial crosscutting R&D.
- Facilitate interaction between the researchers developing improved process control technologies and potential IOF users. These interactions could include technical progress reviews of crosscutting R&D programs and technology workshops to discuss technical developments and identify opportunities for validating and implementing them.

Technology Transfer among Industry Sectors

The panel identified crosscutting R&D that could benefit several industries without redundancy. However, the process development and implementation phases will be unique to particular processes or conditions and could be addressed best by the interested IOF groups. Some industry-specific tasks are listed below:

- the development of road maps to identify technology needs and implementation plans
- interaction with crosscutting technology programs (e.g., technical workshops and R&D progress reviews)
- the development and validation of process models related to specific key processes that would facilitate moving from environment-level to in-situ-level control schemes
- the development of actuators to control specific key process variables
- the optimization of process control systems, especially using supervisory controllers and plant-wide integration
- the validation and implementation of improved sensor technologies and process control systems in large-scale processes

Finally, the panel recommended that OIT continue to coordinate interagency and intra-agency progress and plans in complementary technologies to avoid duplications. In addition to monitoring complementary programs, the panel recommended that OIT collaborate with four other organizations.

- National Institute of Standards and Technology, which is developing standards for open-architecture systems. IOF industries should evaluate and validate system standards for large-batch and continuous operations.
- National Science Foundation (NSF), which is sponsoring research centers to develop improved process sensing and process modeling capabilities. IOF industries should coordinate the implementation and application of process modeling and advanced sensor technology.
- Department of Defense (DOD) especially the Defense Advanced Research Projects Agency (DARPA), which is developing microelectromechanical (MEMS) devices, fabrication processes, and applications. IOF industries should evaluate MEMS devices for sensing/control of industrial processes.
- DOD programs (especially Army, Navy, and DARPA), which are developing condition-based maintenance approaches. IOF industries should evaluate sensors and diagnostics developed to monitor processing equipment and machinery.

CASE STUDY 3: INDUSTRIAL SEPARATION PROCESSES

Separation processes (i.e., processes using physical, chemical, or electrical driving forces to isolate or concentrate selected constituents from a mixture) are essential to the chemical, petroleum refining, and materials processing industries. In addition to the important process roles that separation technologies play in each of these industries, separation technologies present opportunities for reducing waste and using energy and raw materials more efficiently. New developments in separation technologies are, therefore, critical for the continued productivity and global competitiveness of U.S. industries.

The Panel on Industrial Separation Processes was established to identify the most important needs for separation processes in the IOF; to identify separation technologies that can meet these needs, especially technologies that are applicable to two or more industries; and to suggest criteria for identifying and prioritizing research and development in separation technologies. Industrial separations was selected as the third study under CITA because separation process technologies were identified by several of the industry visions as important enabling technologies. The panel's findings include a summary of the separation process needs of individual IOF industries, as well as a discussion of research opportunities to meet these needs (NRC, 1999). The major recommendations are included in the summary below.

Key Needs for Separation Processes

The panel included in its analysis the seven IOF industries involved in the program at the beginning of the study (chemicals, petroleum refining, aluminum, steel, metalcasting, glass, and forest products) and identified specific separation needs for each of these industries. Although a number of areas were identified where separation issues affected more than one industry, the panel concluded that the needs of these industries warranted individual treatment. In fact, the panel found that many important separation problems were unique to a particular industry.

Crosscutting Research Opportunities

Although separation technologies were essential to all seven IOF industries, the panel found few opportunities for crosscutting research because of the diversity of raw materials, product forms, and processing conditions in these industries. The panel, therefore, concluded that OIT's program would not be significantly more efficient by establishing a single crosscutting research program in separation technologies.

Nevertheless, relatively well developed technologies in one industry might be transferable to another industry. In addition, a few technology areas were relevant to more than one, in some cases all, of the IOF industries. Therefore, the panel recommended that the technical program managers at OIT coordinate the results of separations research among the IOF industries, and monitor and disseminate the results. The panel identified five opportunities for coordinated programs:

separation processes for the chemical and petroleum refining industries; bulk sorting technologies for the materials processing industries (especially aluminum, steel, metalcasting, glass, and the polymer-recycling sector of the chemical industry); separation technologies for dilute gaseous and aqueous waste streams; drying and dewatering technologies; and lower cost oxygen production processes.

Separation Processes for the Chemical and Petroleum Refining Industries

A number of issues are common to the chemical and petroleum refining industries. In addition to general improvements in process efficiency, the panel identified two separation technology areas that could meet a number of needs in these industries:

- separation methods using multiple driving forces, including processes in which a naturally occurring driving force for a specific operation is enhanced by an intervention that changes the system thermodynamics or where two or more separation techniques are combined (e.g., membrane separation and distillation, affinity-based adsorbent separation, and electrically aided separation)
- separations associated with chemical reactions, in other words, methods that combine reaction and separation in one process step (e.g., reactive metal complex sorbents and chemically facilitated transport membranes, combined chemical synthesis and separation processes, membrane reactors, and electrochemical methods of separation)

Bulk Sorting Technologies for the Materials Processing Industries

A number of the materials processing industries (aluminum, steel, metalcasting, glass, and the polymer-recycling sector of the chemical industry) identified separation needs that can be classified as materials handling and sorting, specifically, the high-speed separation of scrap. R&D in this area should focus on making processes more economical. Improved high-speed sorting technologies, such as air-jet and conveyer-belt technologies, would serve this purpose. R&D should explore the following areas:

- on-line sensors for high-speed analysis of the composition of streams and the makeup of individual objects in these streams
- physical separation techniques, including gravity separations (e.g., air-jet and flowing-film separation), froth flotation, magnetic separations, and electrical separations (e.g., electrostatic separation and tribo-electrification)
- high-speed sorting technologies, including the fundamental mechanics of high-speed conveying, techniques to position individual scrap pieces in sequential arrays before analysis, and methods for physically diverting the analyzed pieces by material type

Dilute Gaseous and Aqueous Streams

All of the IOF industries identified the separation of components from dilute gaseous streams, dilute aqueous streams, or both, as important needs. Areas with potential for crosscutting research include the following:

- methods for separating components from dilute gaseous streams, such as adsorption, high-selectivity membranes, inorganic membranes, and advanced-particle-capture technologies for the removal of micron-sized particles
- methods for separating components from dilute aqueous streams, such as reactive metal complex sorbents, reducing agents, air oxidation combined with absorption, membranes, steam and air stripping, electrically facilitated separations, destructive-oxidation techniques, electrodialysis, ion exchange, and crystallization

Drying and Dewatering Technologies

Several industries identified separation needs that could be met by improvements in drying and dewatering technologies. Examples include: the removal of solvents from polymers (devolitalization) in the chemical industry; the removal of entrained water from crude oil and the drying of natural gas in the petroleum refining industry; the drying of ceramic casting materials and reclamation of sand in the metalcasting industry; the drying of paper in the forest products industry, and the drying of sludge from waste-gas scrubbing and wastewater treatment.

Lower Cost Oxygen Production

The chemical, petroleum refining, aluminum, steel, and glass industries all indicated that lower cost oxygen would be beneficial to them in combustion and other processes. Currently, the high cost of oxygen is a significant barrier to the widespread use of several emerging technologies.

Enabling Technologies

The panel identified several enabling technologies that, although they are not separation processes, could be used to improve industrial separations. Research areas include new membrane materials, sorbent materials for specific applications, on-line diagnostics and sensors, an improved understanding of thermodynamics, and particle characterization. The panel recommended that OIT focus long-term, fundamental research on these areas.

Recommended Criteria

Based on the research opportunities identified by the panel for each industry and the maturity of separation technologies, the panel identified four general criteria for selecting R&D projects:

- Time scale. Research in this area should focus on high-impact technologies that have been demonstrated in the laboratory and will be ready for commercial application in five to seven years.
- Crosscutting criteria. OIT should only support crosscutting research in separation technologies that are either (1) embryonic technologies that could lead to major advances in several industries or (2) improvements in mature, high-use technologies where incremental improvements could have a substantial effect.
- Impact on existing processes and equipment. Proposed projects should be evaluated for the potential economic impact of a new separation method and for the potential effect of that new method on existing processes and equipment.
- New technologies. Projects for the development of new separation technologies should be multidisciplinary and should be scaleable to production volume, both in technical and economic terms.

CONCLUSIONS AND LESSONS LEARNED

Crosscutting Initiatives

Based on these case studies and a review of existing OIT programs, the committee identified four types of crosscutting technologies:

- crosscutting technologies in name only that have little overlap or synergy among the identified needs of the IOF industries, even though they may have similar nomenclature
- existing projects that predate the IOF strategy that have been relabeled as crosscutting
- crosscutting technologies that do not have a critical mass of support in any IOF industry but are considered somewhat important to several of them
- research of significant interest to several IOF industries that can be more efficiently managed and leveraged if they are merged into a crosscutting program

Of these, only the last type is consistent with the IOF strategy.

Recommendation. OIT should establish crosscutting technology initiatives only if it would make the overall program significantly more efficient.

Crosscutting research opportunities are often related to either (1) embryonic technologies that have the potential for major advances in multiple industries or (2) more mature, high-use technologies where incremental improvements could have a substantial effect. Research that would benefit many industries is often more fundamental than the research generally undertaken by OIT, especially in the IOF program. If OIT relies only on industry-identified needs, potential crosscutting or exploratory research opportunities may not be supported. The committee believes that continued collaboration and coordination with basic and applied research organizations will be critical to the future relevance of the OIT program.

Recommendation. OIT should increase the level of collaboration with other Department of Energy offices (e.g., Basic Energy Sciences, other applied program offices, or relevant national laboratories) in crosscutting research programs.

Managing Crosscutting Initiatives

The committee believes that it will be difficult for OIT to manage crosscutting initiatives within the IOF framework in a way that facilitates the development of specific R&D performance goals based on the common needs of several industries.

Recommendation. To identify and prioritize crosscutting research to meet the needs of the IOF industries, OIT should (1) establish a coordination group in each crosscutting technology area to develop short-term and long-term goals and to monitor the progress and results of research and (2) facilitate interaction between the researchers and potential IOF users (e.g., technical progress reviews, technology workshops).

Recommendation. OIT should emphasize the early involvement of key industrial participants in crosscutting programs, including suppliers, producers, and users of particular materials or process technologies.

Metrics

Even though the OIT program has relied on industrial participants to establish needs and priorities, the “profit-based” metrics used in industry to measure the efficacy of R&D may not be appropriate for measuring progress in government-funded long-term research.

Recommendation. OIT should adopt metrics compatible with the Department of Energy and OIT organizational objectives for comparing and selecting crosscutting programs for the IOF program. These metrics should include (1) the potential for reducing the consumption of energy and raw materials and for reducing waste, (2) consistency with the technology road maps of the IOF industries, (3) commercial potential/ market value, and (4) potential use in more than one industrial sector.

4

Assessment of the IOF Approach

The objective of OIT's research programs is to work with U.S. industry to improve energy efficiency, reduce waste, and increase productivity. The IOF strategy is intended to improve OIT-industry partnerships, ensure the relevance of research projects, encourage industry participation, and facilitate the commercialization of developed technologies. The stated long-term goals of OIT are to achieve a 25 percent improvement in energy efficiency and 30 percent reduction in emissions for the IOF industries by 2010 and a 35 percent improvement in energy efficiency and 50 percent reduction in emissions by 2020 (OIT, 1998a). The elements of OIT's strategic plan are listed below:

- focus on energy-intensive and waste-intensive industries
- establish partnerships with industry
- apply the IOF strategy to direct industry and government resources to areas of greatest need
- support new "vision" industries
- use integrated teams to accomplish program goals
- design flexible and responsive programs
- strengthen the education and training of OIT staff
- monitor progress and performance
- conduct comprehensive planning to guide future program strategy

The present study focuses on OIT's transition to the IOF strategy. To implement the strategy, OIT has: (1) facilitated the preparation of industry visions and technology road maps, (2) initiated cooperatively funded R&D projects identified in the visions and road maps, (3) conducted generic (or crosscutting) R&D projects, and (4) disseminated research results and program benefits. The committee's assessments of OIT's program implementation and management are presented in this chapter.

IMPLEMENTATION

Visions and Road Maps

The committee believes that the most significant accomplishment of the IOF initiative has been the development of a consensus by industry groups on research priorities through the preparation of industry visions and technology road maps. However, vision documents and road maps must be "living documents," that is, flexible enough to accommodate changes in the technological and business climate. Maintaining the consensus by updating the industry vision and technology road maps will be critical to the future of the IOF program. Examples of how current processes benefit all stakeholders are listed below:

- Industries are gaining monetary support for research that they have determined to be important.
- DOE is funding high-priority research projects needed by industry and is no longer perceived as funding projects arbitrarily.
- "Industry research agendas" assure researchers that their research is important to the industry.
- Government *and* industry share the cost of research.
- Researchers and their universities or not-for-profit organizations have intellectual property rights under the Bayh-Dole Act of 1980 (P.L. 96-517).

Agriculture

The agriculture IOF team, established in late 1997, has issued a vision document for plant/crop-based renewable products based on a workshop initiated by the National Corn Growers Association (OIT, 1997a). The DOE-industry compact was signed on February 23, 1998. The goals set forth in the vision document include the following:

- Displace at least 10 percent of petroleum with plant/crop resources as the basic building block for consumer products by 2020 and provide the concepts needed to displace as much as 50 percent by 2050.
- Establish a plant/crop-based manufacturing infrastructure.
- Establish partnerships between industry, government, and academia for R&D that can lead to market opportunities and ensure that processes and systems are commercially viable.

Two road-mapping workshops were held in mid-1998 to focus on uses of existing crops and modified plants, which was a key technology identified in the vision. The road map was published in February, 1999 (OIT, 1999).

Aluminum

The aluminum industry, represented by The Aluminum Association, published its vision document in March 1996 (Aluminum Association, 1996). A compact to undertake collaborative research to meet the vision goals was signed in October 1996. The industry developed a technology road map, which was published in June 1997 (Aluminum Association, 1997). Subsequently, a road map to address one of the industry's most pressing needs, the development of inert anode technology was published (Aluminum Association, 1998) (see Figure 4-1). The aluminum team has issued proposal solicitations for fiscal year (FY)98 and FY99 through DOE for research that addresses the needs identified in the road maps.

Chemicals

The chemicals industry, represented by the American Chemical Society, the American Institute of Chemical Engineers, the Chemical Manufacturers Association, the Council for Chemical Research, and the Synthetic Organic Chemical Manufacturers Association, published its vision document in December 1996 (ACS, 1996). The vision identifies four critical technology areas for the chemical industry:

- new chemical science and engineering technologies
- supply-chain management
- information systems
- manufacturing and operations

A memorandum of understanding was signed on February 26, 1997, with DOE to establish a framework to identify appropriate areas for collaborative R&D and technology demonstration. Road maps are being developed to address technology areas identified in the vision document. Road maps that pertain to catalysis (Haynes, 1997), separations (CWRT, 1998), computational fluid dynamics (LANL, 1998), and materials of construction (MTI, 1998) and draft visions for bioprocesses and computational chemistry have already been developed. The interim report from the Workshop on Process Measurement and Control: Industry Needs has also been completed. (Doyle, 1998). The chemicals team has issued proposal solicitations for FY99 to address these specific areas.

Forest Products

Forest products was the first IOF industry group to develop its vision in November 1994 (AF&PA, 1994). The vision was developed by a group of Chief Technology Officers (CTOs) from U.S. pulp and paper companies and was endorsed by a working group of Chief Executive Officers (CEOs) for the American Forest and Paper Association (AF&PA). Robert C. Williams, then CEO of James

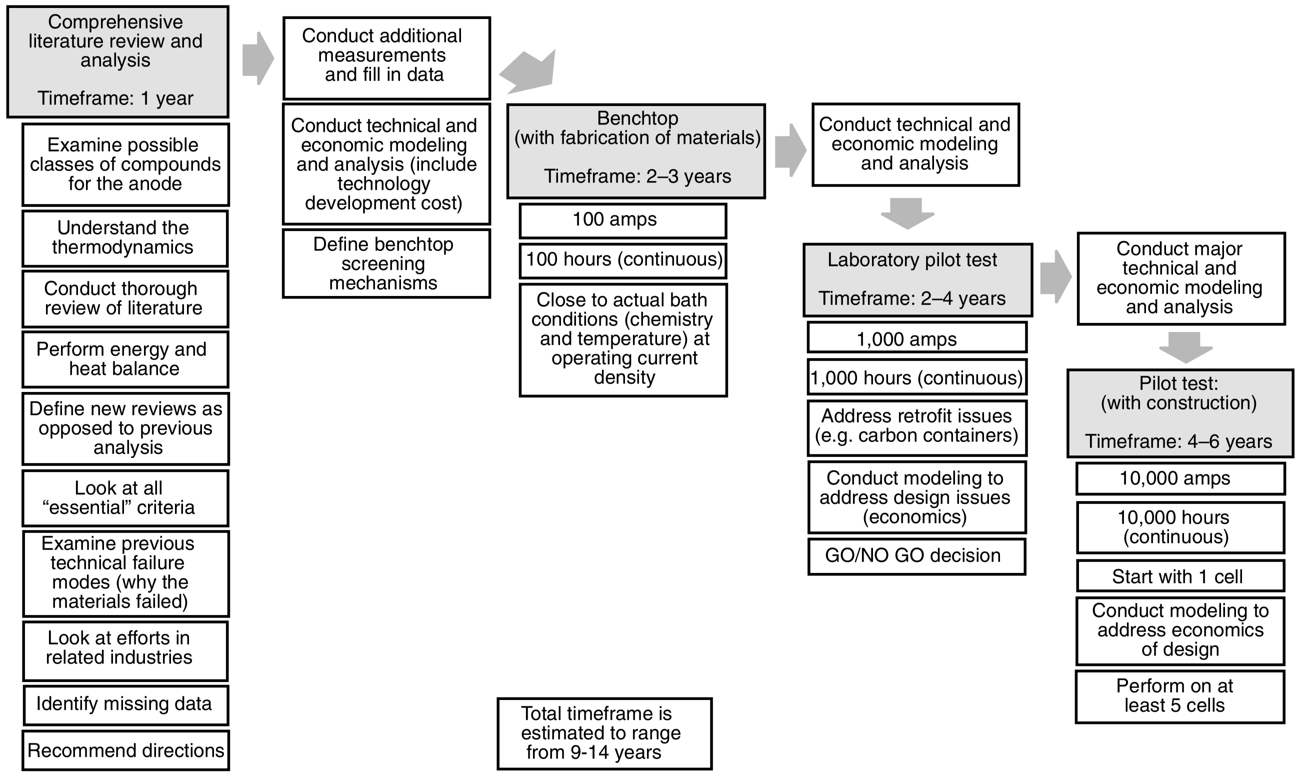

FIGURE 4-1 Aluminum industry summary road map for the development of inert anode technology. Source: Aluminum Association, 1998.

River Corporation, representing the U.S. industry, signed a compact with DOE, represented by then Secretary of Energy Hazel O'Leary, in November 1994.

Six working groups were formed (one for each technology area—environmental performance, recycling, sustainable forestry, sensors and controls, energy performance, and improved capital effectiveness). Several of the groups were able to get quick starts on high-priority research because similar activities were already under way (sponsored by the Technical Association of the Pulp and Paper Industry). Each working group developed a portfolio of "Research Pathways," an example of which is shown in Figure 4-2.

Each working group has developed procedures for soliciting proposals from researchers in academia, industry, and the national laboratories and a selection process for choosing research that addresses the designated needs. The recommendations from the working groups are then passed to a committee of CTOs, who either eliminate proposals or endorse them and submit them to OIT. OIT makes the final decision as to whether or not to fund a proposal.

Glass

The glass industry published its vision in March 1996 [http://www.oit.doe.gov/glass/page9.html]. The industry goals established in this vision are listed below:

- reduce production costs by 20 percent (compared with 1995 levels)
- recycle 100 percent of all glass products
- reduce process energy use by 50 percent
- reduce air and water emissions by 20 percent
- recover and recycle 100 percent of available post-consumer glass
- achieve "six sigma"[1] quality through automation, process control, optimized glass composition and strength, and computer simulation
- create innovative products that broaden the marketplace
- increase supplier and customer relationships in raw materials, equipment, and energy savings

A compact between DOE and industry representatives—Anchor Glass Containers, Carr Lowrey Glass Company, Certainteed Corporation, Corning, Ford Motor Company, the Glass Packaging Institute, and the Society of Glass Science and Practices—was signed on April 29, 1996. An industry road map that addresses the four principal industry segments—flat glass, container glass, fiberglass, and specialty glass—has been published (Energetics, 1997).

[1] "Six sigma" is an ambitious quality goal to reduce the incidence of process errors to near zero. It is an outgrowth of General Electric Company's Six Sigma Quality Campaign and has found broad support in the process and computer industries (Melymuka, 1998). The term is a statistical measure of quality, based on the occurrence of defects.

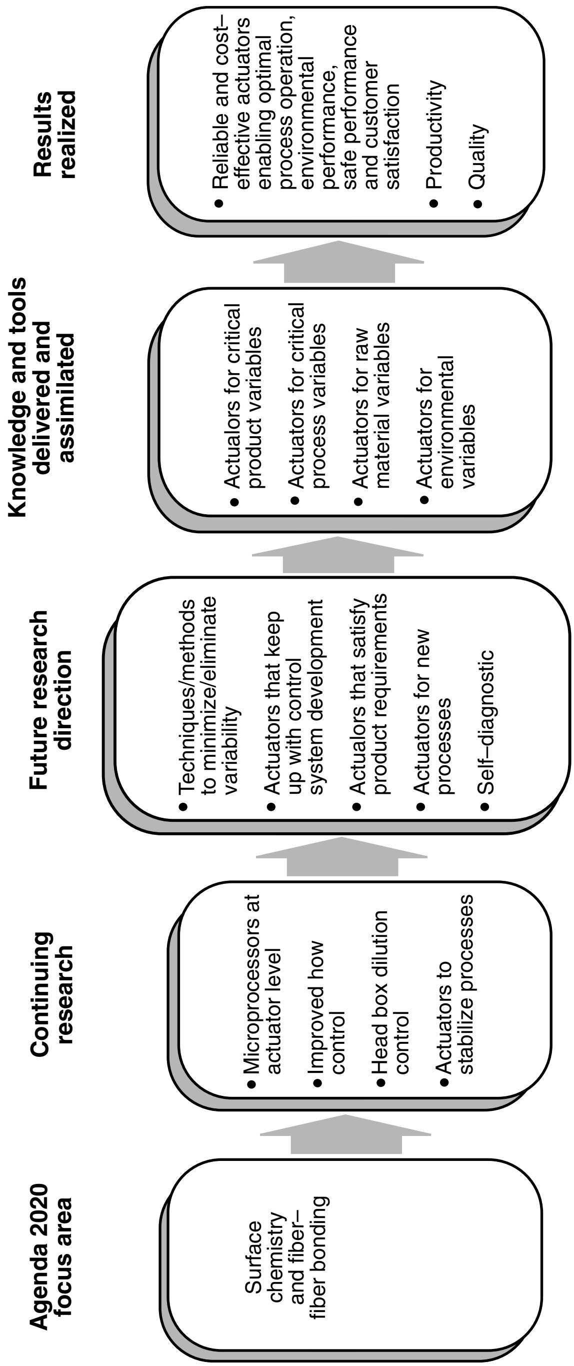

FIGURE 4-2 "Pathway" (road map) for the forest products industry. Source: http://www.oit.gov/forest/pathways.

Metalcasting

The metalcasting industry, represented by the American Foundry Society, the Steel Founder's Society of America, and the North American Die Casting Association, published its vision in September 1995 (CMC, 1995). The Cast Metals Coalition (CMC) was established to provide direct partnership with DOE. A compact was signed with DOE in October 1995 to establish a framework to identify areas for collaborative R&D and technology demonstration. In 1998, the CMC published a technology road map, which establishes near-term, midterm, and long-term technology goals (CMC, 1998) in several key areas, including (1) products and markets, (2) materials technology, (3) manufacturing technology, (4) environmental technology, (5) human resources, and (6) industry health.

As required in the Metal Casting Competitiveness Research Act of 1990 (P.L. 101-425, 104 Stat. 915, 15 U.S.C.§5301-09), the program is managed by OIT. The CMC, through its executive board and technical committees, oversees the IOF R&D. Projects are reviewed by the CMC technical committees, which select candidate projects based on the road map and vision document. The CMC Executive Board (which includes representatives of the three industry associations, OIT, and the metalcasting Industrial Oversight Panel) makes the final selections.

Mining

The mining industry is the newest industry group in the OIT program. The National Mining Association (NMA) represents the industry, which includes coal, metals, and minerals concerns. The industry vision document was published in September 1998 (NMA, 1998a), and the first of several road mapping sessions was held in October 1998, producing a road map for crosscutting (NMA, 1998b). A solicitation for R&D projects to support the identified industry needs is being developed.

Petroleum Refining

Petroleum refining was one of the original IOF industries. In 1997, the group, which was organized through the American Petroleum Institute (API), disbanded. The industry group was reestablished in 1998. Efforts are under way to establish research priorities and road maps. Recent developments include the release of a report presenting benchmark energy use and environmental data for the petroleum refining industry (OIT, 1998b). API has completed the downstream industry vision, which is currently being reviewed by API committees.

Steel

OIT has been working with the steel industry for more than a decade, beginning with the Steel and Aluminum Energy Conservation and Technology

Competitiveness Act of 1988 (P.L. 100-680; 15 U.S.C. 5101 *et seq.*), the so-called Metals Initiative. The steel industry's IOF participation was organized through the AISI and the Steel Manufacturers Association. The industry vision document, published in 1995 (AISI, 1995), identified four areas that would be critical to competitiveness over the next 20 years: production efficiency, recycling, environmental engineering, and product development. A compact was signed with DOE in May 1995 to establish guidelines for industry-government partnerships.

A technology road map was developed and published in 1997 and updated in 1998, to establish research priorities (AISI, 1997, 1998). Much of the current research portfolio is part of the Metals Initiative. The industry has issued separate solicitations for industrial researchers (in partnerships with university and national laboratories) and for DOE national laboratories. Industrial reviewers evaluate research proposals based on the technology road map.

Summary

The committee believes that vision statements and road maps are not ends in themselves. These documents must be maintained, updated, and acted upon to achieve the technology advancement goals they describe. Industry-generated technology visions and road maps naturally address issues besides energy and waste reduction. Therefore, the long-term challenge for OIT will be to keep these documents up to date and to maintain the industries' interest in addressing all of the identified needs, not just the ones that receive OIT support. The committee believes that the vision and road map processes would probably not continue without government stimulation and financial support for the defined technology development needs.

Recommendation. OIT should maintain and update the road maps and vision statements regularly (annually or bi-annually) to reflect changes in industry objectives, technologies, and the business climate.

Industry Participation

One of the primary motivations for the IOF strategy is to increase the participation of industry groups in the OIT program by making research more relevant to industry. A measure of industry participation used by federal agencies, including DOE, is the level of industry cost-sharing in federally funded research. Most of the solicitations for industry-specific R&D specify a cost-sharing target (e.g., aluminum industry solicitations require 30 percent cost sharing; [http://www.oit.doe.gov/IOF/aluminum/aluminum.html#solicitation]).

OIT provided the committee with a summary of the status of IOF-specific research projects and cost sharing (see Table 4-1). The current projects were divided into three categories indicative of the incomplete transition to the IOF strategy. The categories are:

TABLE 4-1 Status of Industry Cost Sharing for IOF-Specific Projects (as of October 1998)

Vision Industry	Number of Projects	DOE funding ($K)	Cost Share ($K)	Percentage of Cost
Aluminum	16	9,960	14,070	59
	6 pre-vision, pre-road map	5,630	4,770	46
	3 post-vision, pre-road map	720	3,550	83
	7 post-vision, post-road map	3,610	5,750	61
Chemicals	9	10,540	10,540	50
	5 pre-vision, pre-road map	2,480	1,720	41
	4 post-vision, pre-road map	8,060	8,820	52
	0 post-vision, post-road map	0	0	0
Metalcasting	20	6,340	7,570	54
	7 pre-vision, pre-road map	3,030	3,920	56
	11 post-vision, pre-road map	2,610	2,690	51
	2 post-vision, post-road map	700	960	58
Glass	10	9,180	5,430	37
	5 pre-vision, pre-road map	3,230	1,830	36
	3 post-vision, pre-road map	4,630	1,530	25
	2 post-vision, post-road map	1,320	2,070	61
Forest Products	57	32,045	18,020	36
	8 pre-vision, pre-road map	12,290	8,490	41
	15 post-vision, pre-road map	825	930	53
	34 post-vision, post-road map	18,930	8,600	31
Steel	15	23,670	13,990	50
	2 pre-vision, pre-road map	13,780	7,210	34
	4 post-vision, pre-road map	690	2,680	79
	9 post-vision, post-road map	9,200	4,100	31
Total	127	91,730	69,640	43
	33 pre-vision, pre-road map	40,440	27,950	41
	40 post-vision, pre-road map	17,530	20,200	54
	54 post-vision, post-road map	33,760	21,490	39

Source: OIT.

- projects started before an industry vision document or technology road map was developed (pre-vision, pre-road maps)
- projects started after the release of the industry vision document but before completion of technology road maps (post-vision, preroad maps)
- projects started after the industry vision document and road maps were released (post-vision, post-road maps)

Surprisingly, the percentage of industry cost-sharing did not increase significantly as expected under the IOF strategy. This could be because, in addition to cost-shared contracts, OIT has emphasized other mechanisms to partner with industry, including cooperative research and development agreements, R&D consortia, exchange programs, user facility agreements, and work-for-others agreements. In addition, some industry groups (e.g., forest products) have suggested that DOE focus their funding on academic research, while the industry performs other work identified in the road maps on their own (outside of the IOF program).

It will be very difficult for OIT to keep track of all types of industry research that results from the vision and road map processes, and the committee believes that the impacts of industrial research related to the industry vision documents and road maps might not be accounted for. Because OIT offers a wide range of options for industry participation, they should develop methods of tracking the status of all types of industry participation in the IOF program.

Research Projects

OIT divides its R&D into three categories: IOF-specific programs, crosscutting technology programs, and technology access programs. This section discusses the OIT research portfolio, including the balance of industry-specific and crosscutting research programs.

Overall Program

OIT's FY98 budget for the IOF program was $101.8 million, up about $16.1 million over FY97. Of the 1998 total, $49.1 million (48.2 percent) is devoted to "crosscutting" technologies. The balance, $52.7 million, comprised industry-specific line items related to the IOF vision statements and road maps. The crosscutting category included major projects involving co-generation, advanced materials, and continuous-fiber ceramic composites.

OIT also has a variety of technology access programs, totaling $26.3 million, and a small program ($3.0 million) on biomass turbine fuels. Finally, management and planning for all OIT activities is budgeted at $7.7 million, bringing the total FY98 budget for OIT to $138.9 million.

The IOF budget for FY99 is $166 million, an increase of $30 million over FY98 and an increase of $14 million over FY97; thus the budget has been growing. The major growth area for FY99 is in the crosscutting programs, as can be seen from Table 4-2. There was also a small (8 percent) increase in IOF-specific programs.

The recent review of progress in DOE's R&D by the President's Committee of Advisors on Science and Technology (PCAST, 1997) recommended that the FY99 budget be $185 million; the review recommended that the budget for IOF-

TABLE 4-2 Budget Trends for OIT Program Areas (in $ millions)

	FY97 Appropriation	FY98 Appropriation	FY99 Requested	FY99 Enacted
Industries of the Future (Specific)	45.3	53.1	76.0[a]	57.4
Industries of the Future (Crosscutting)	38.4	49.1	49.4	71.2
Technology Access	24.8	26.2	32.0	28.8
Management and Planning	6.9	7.7	9.2	7.9
Totals	115.4	136.2	166.6	165.9

[a]Includes a planned industry-wide solicitation to reduce the generation of climate change gases, which was not supported by Congress.

Source: OIT.

specific projects be increased from $53 to $65 million and the budget for crosscutting programs be increased from $49 million to $70 million.

In general, the crosscutting projects are larger than the IOF-specific projects. For example, in FY97 the forest products group had $10.8 million for 33 projects, ranging from $22,000 to $3.5 million. The aluminum industry had $5.6 million for 8 projects, ranging from $200,000 to $2.5 million.

Recommendation. OIT should perform a "portfolio analysis" to evaluate its overall research program. The analysis should include technical risk, potential payoff (in terms of energy savings and waste reduction), and time frame (near-term or long-term). The overall portfolio balance should be considered in the evaluation, as well as the prioritization of research projects; projects should be added or trimmed to balance the portfolio, as necessary.

IOF-Specific Research

The funding levels for IOF-specific research for each industry is shown in Table 4-3. Trends in funding reflect the industry groups' progress in developing their vision documents and road maps to establish their research priorities. For example, the 82 percent increase for industry-specific research for the aluminum industry from FY97 to FY99 reflects the industry's road maps and established priorities, which facilitated the solicitation of research proposals.

Now that most of the industry groups have finished at least preliminary road maps, OIT will have to develop a rational process for allocating limited funds among the IOF industries to support their identified needs. If the process appears to be arbitrary, the industry participants could consider the allocation process a competition among the industry groups. Allocation schemes should assess the technical needs and priorities of each group and consider factors such as the size of the industrial community, the potential effects of the research on OIT goals, the ability of the industry to support implementation of the technology, and other potential sources of support.

Recommendation. OIT should establish a rational, transparent process for allocating funds among IOF industries and then allow them to set project directives based on their road maps, as long as the projects are consistent with OIT's mission.

Previous attempts to use input from industry representatives to identify research priorities to improve their competitiveness have been criticized in Congress as "corporate welfare." For example, DOD's Technology Reinvestment Program and the National Institute of Standards and Technology's Advanced Technology Program were criticized for inappropriately aiding commercial industry. The principal lesson to be learned from these experiences is that "it is inappropriate for the government to undertake product development without a compelling national mission" (Denman, 1996). In the past, OIT has effectively focused on applied research and technology development that furthered DOE's goals of energy efficiency and waste reduction. The committee is concerned that allowing industry groups to set program priorities could shift the focus toward near-term product development or lose sight of DOE's mission.

New industries have recently joined the IOF (agriculture in 1997 and mining in 1998). The committee believes that increasing the number of industry groups can be an effective way to expand the IOF program as long as the new industries meet the initial criteria, that is, they are large energy consumers and industrial waste producers.

Recommendation. OIT should continue to apply its criteria of energy consumption and waste generation in selecting industries for participation in the IOF program.

TABLE 4-3 Trends in IOF-Specific Allocations (in $ millions)

	FY97 Appropriation	FY98 Appropriation	FY99 Enacted
Forest and Paper Products	10.8	12.0	11.9
Steel	8.9	9.7	10.5
Aluminum	5.5	7.3	10.0
Metalcasting	3.4	5.5	5.7
Glass	2.9	3.9	4.8
Chemicals	10.0	11.6	14.5
Petroleum Refining	3.7	3.0	0
Totals	45.3	53.0	57.4

Source: OIT

Crosscutting Technologies

In Chapter 3, the committee identified four types of potential crosscutting technologies. The current program includes two of the four types: (1) existing projects that predate the IOF strategy that have been relabeled as crosscutting (e.g., AIM, CFCC [Continuous-fiber ceramic composites], and ATS [advanced turbine systems]) and (2) projects of significant interest to several IOF industries that could be more efficiently managed and leveraged if they were merged into a crosscutting program (e.g., sensors and controls). The committee believes that only the second of these types is consistent with the IOF strategy. The recommendations in Chapter 3 relate to the committee's suggested approach to managing crosscutting programs.

Crosscutting programs that predate the IOF strategy include major initiatives, such as the ATS program, which is now part of a combined heat and power global climate change initiative, and the more mature CFCC and AIM programs. Although the committee did not evaluate these programs in detail, they do not necessarily fit in with the IOF philosophy because they are not the result of the vision and road map processes. The committee recommends that these initiatives be either (1) managed separately from the IOF-specific projects or (2) re-evaluated and brought within the IOF framework.

Recommendation. To complete the transition to the IOF strategy, OIT should shift the balance of IOF-specific and crosscutting research to emphasize industry-specific work identified on industry road maps. Industry participation in the management and evaluation of crosscutting research programs should be expanded.

The committee recognizes that relying on "market pull" to define R&D objectives has inherent drawbacks. One of the drawbacks is that important research on technologies that could potentially benefit many industry groups but that are not a primary concern to any one of them is likely to go unfunded. A "market pull" strategy has no simple, self-reinforcing mechanism for identifying promising crosscutting programs.

Recommendation. OIT should adopt the following approach to managing crosscutting programs within the IOF strategy:

- Develop a consensus among the IOF industries that a certain percentage of R&D funds should be allocated for basic science and the development of crosscutting technologies.
- Using established management procedures, define and select a recommended list of basic/crosscutting technologies for development.
- Review these recommendations with the IOF industry groups, and solicit support and feedback.

Role of the National Laboratories

The DOE national laboratories have been important in conducting research and managing interdisciplinary projects in the OIT program, especially in the legacy crosscutting technology areas (e.g., AIM, CFCC, and ATS). However, since the implementation of the IOF strategy, the national laboratories have had to reposition themselves in the OIT program by teaming with industry and responding to the needs established in the IOF road maps.

OIT was instrumental in the establishment of the Laboratory Coordinating Council (LCC) in 1995 to provide industry with information on laboratory capabilities in specific technologies and to facilitate collaborations with industry by matching laboratory capabilities with industry needs (Chum, 1997). The LCC includes representatives of the following organizations: Albany Research Center, Ames Laboratory, Argonne National Laboratory, Brookhaven National Laboratory, Federal Energy Technology Center, Idaho National Energy and Engineering Laboratory, Kansas City Plant, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, National Institute for Petroleum and Energy research, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratories, Savannah River Technology Center, and the Y-12 Plant.

The LCC, which was established to facilitate interactions between the national laboratories and the IOF industry groups, has developed separate mechanisms for interacting with each industry group and for addressing crosscutting areas. The LCC has developed matrices of laboratory competence for specific technical areas to provide industry with links to capabilities in the national laboratories and to coordinate responses to industry research initiatives among the interested laboratories.

Even with the improved coordination provided by the LCC, the national laboratories have found it difficult to align their programs with near-term, industry-specific programs. The laboratories feel that their strengths are better suited to long-term, crosscutting initiatives. The use of "market pull" strategy has shifted the emphasis toward industry-specific technology development and implementation at the expense of crosscutting technologies.

Technology Transfer

Before 1995, R&D management at OIT was "science driven" or "technology-push driven." Although this approach led to many technological successes, transitioning technology to the commercial sector was difficult to document and, in many cases, was not done. Independent, expert review panels or committees, the members of which were often distanced from the front lines where technologies were transferred from the laboratory to commercial use, provided direction and oversight.

In the transition to the IOF strategy, OIT made a commitment to increase and document the commercial impact of OIT programs provided they still met the overall goals of improving energy efficiency and reducing waste generation. To accomplish this mission, OIT recognized that its R&D management strategy had to change from a "technology push" to a "market pull" strategy. The two key questions however were (1) which markets should be served, and (2) how the market-pull could be harnessed. To answer the first question, OIT ranked industries according to their level of energy consumption and waste production, the linchpins of the IOF strategy. The second question is the subject of this section.

By soliciting IOF feedback on basic and crosscutting technologies, industry is able to exert a market pull on OIT's programs. This was a necessary, but not sufficient, condition of successful technology transfer. The commercialization of a new technology is a difficult and risky proposition even for corporations that specialize in, and depend on, commercialization. Every established materials or manufacturing company in the world has a long list of failed attempts to commercialize new technologies, and the failures usually outnumber the successes. It may be, therefore, inappropriate for a government program to measure its R&D success against the direct metrics of technology transfer and commercialization.

In the usual sense of the word, "commercialization" implies one of two possibilities. Either the embodiment of a technology must be sold directly to a market in a way that is both profitable and sustainable without corporate or government subsidies, or it must be incorporated into a component or system that is similarly sold. To be a commercial product, someone must be earning money from selling it. In most corporations, the activities required to commercialize a new technology are spread among many groups, although they are concentrated in the sales, marketing, and new business development organizations. Although these groups do not follow standard commercialization procedures, they all go through similar stages in the commercialization process:

- develop the technology
- sample it with selected "key" customers
- perform market research/develop an internal commercialization plan
- establish pilot-scale production facilities or find outside production sources
- develop promotional materials (brochures, etc.)
- "launch" the new product with sales promotions
- train internal and external sales personnel in the use and benefits of the technology

At every stage of commercialization, the proponents of a new technology must solicit, defend, and secure corporate commitment and funds to advance to the next step. For new materials technologies, the process generally takes years, often decades. Because OIT has no profit motive or profit-making capabilities, it cannot fully participate in the commercialization process. Therefore, the final stages of the commercialization of technologies developed by OIT must be left to a third party.

Recommendation. Although successful commercialization cannot be assured, the committee believes that the following actions will improve the probability of commercial success:

- Maintain regular interactions with all critical stakeholders in the supply chain through all stages of program development, including raw material suppliers, parts makers, and systems integrators.
- Publicize the technical accomplishments of the program at popular trade meetings, and use these meetings to meet and network with technical and business people.
- Establish networks that include not just technical people, but also sales, marketing, and senior management personnel.
- Expose technical personnel to basic business principles, including elements of cost estimation, value analysis, and market research. Insist that rudimentary business plans accompany each later-stage R&D program and have these plans critically reviewed by industry stakeholders.
- Selectively subsidize and participate with third-parties in programs to demonstrate and de-bug the technology. These activities should not be confused with commercialization, however, and should be limited to cases where additional technical development is required to enable commercialization. Insertion programs should not be sustained only by government subsidies.
- Recognize that technology development is only one link, albeit an important one, in the chain of commercialization.

Recommendation. OIT should participate directly in a limited number of commercial insertion programs but only for the purpose of identifying remaining technical hurdles.

OIT has a number of technology access programs to validate and commercialize new energy-saving manufacturing technologies. These include open competition grant programs, such as the National Industrial Competitiveness through Energy, Environment, and Economics (NICE[3]) and the Inventions and Innovation (I&I) programs. Other programs are intended to address particular energy and environmental goals. Other technology access programs include the following:

- Motor Challenge, which was established in 1993 to identify and implement technologies to save energy in electric-motor-driven systems
- Climate Wise, a partnership program, jointly sponsored by OIT and the

Environmental Protection Agency, to provide a clearinghouse for technologies that reduce greenhouse gas emissions
- Industrial Assessment Centers, a program that establishes university centers that conduct no-cost energy and environmental assessments of small and medium-sized manufacturing plants

OIT's technology access programs can provide valuable aid to businesses attempting to validate and implement industrial technologies to reduce energy use and waste generation. But all of these programs predate the IOF strategy, and their links to the IOF road maps and priorities are weak. These validation and commercialization programs should be established and planned from the onset of OIT participation to be more effectively integrated with the IOF program.

Recommendation. Validation and implementation programs, such as I&I and NICE[3], should be integrated with the IOF program to improve their relevance in efforts to commercialize OIT-developed technologies identified in IOF road maps.

MANAGEMENT

Role of the Industry Groups in Managing Projects

Representatives of industry groups participate in the management of industry-specific projects according to procedures developed by each individual group. Mechanisms have been established for developing solicitations based on industry road maps; assessing and prioritizing research proposals; and, in some cases, assessing progress and disseminating the results of ongoing projects. The committee believes that a strong industry role in the management of the OIT research portfolio is essential to the success of the IOF strategy.

In Chapter 3, the committee recommended that OIT expand the role of the IOF industry groups in the management of crosscutting research initiatives by establishing coordination groups in each technology area to develop goals and monitor the progress and results of research and by sponsoring forums to facilitate interaction between researchers and potential IOF users. The committee believes that it will be difficult to manage crosscutting initiatives in the IOF framework in a way that facilitates the development of specific performance goals based on the common needs of several industries.

Program Turnover

The success of the OIT program will continue to be measured by the level of industry participation. Implementation of new technologies and a research agenda responsive to changing industry priorities will be the key to maintaining industrial support. OIT and the IOF representatives should continue to replenish the program with new projects. Clear milestones should be identified for each project; the milestones should be monitored and reevaluated at yearly intervals. Projects should be terminated if they meet any of the following criteria:

- all technical goals have been achieved (project is completed)
- goals for technical progress and program expenses have not been met
- industrial support for the technology has been withdrawn

Recommendation. As part of the overall project management process, OIT should develop a mechanism for the orderly termination of (1) projects that have met their objectives and have progressed to the final stage of commercialization (market introduction), (2) projects that have not met goals for technical progress or program expenses, and (3) projects that do not have sufficient industrial interest to support demonstration, process development, and scale-up.

The committee believes that industrial experience for mid-sized to large-sized enterprises that have a mix of technology development and product development could be a guide to managing the project turnover for the OIT program. Industrial research and product development are typically managed over four to five year periods of commitment (i.e., 20 to 25 percent of projects are terminated or completed each year, and a similar number are started) (Wirth, 1996).

Recommendation. OIT should adopt guidelines for program turnover similar to those used by industrial technology-development and product-development organizations.

Communication

OIT has a number of mechanisms for communicating the status and accomplishments of its research programs, including technology workshops, publications to describe programs and partnerships and assess completed research based on energy and environmental metrics (OIT, 1997b), a detailed information site on the Worldwide Web [www.oit.doe.gov], and biannual industrial energy efficiency symposia and expositions. Solicitations are accessible through the Worldwide Web and the network of the industry associations involved in the program, as well as in *Commerce Business Daily*.

Nevertheless, the committee believes that the OIT program could be promoted more effectively. In many cases, the OIT program is the only significant government-sponsored research program focused on process industries. Better promotion of the opportunities and broader dissemination of research results would encourage more industry participation in the program.

Recommendation. OIT should increase its attempts to promote its program by taking the following steps:

- describing technical successes in the trade literature, at technical society and industry trade meetings, in the popular press, and through other high visibility communications media
- promoting industry participation in the validation and implementation of technologies that could lead to commercialization
- describing the program approach, objectives, and levels of industry participation at high-level symposia or forums hosted by the secretary of energy to maintain the interest of industry executives in the program

Metrics

Each of the many approaches to measuring the efficacy of R&D has proponents and detractors, but none is universally, or even widely, accepted. The committee recommends that OIT consider using the following metrics as a basis for comparing and selecting projects:

- potential for energy conservation
- cost/benefit ratio (i.e., risk-adjusted return on investment)
- consistency with IOF business objectives and technology road maps
- commercial potential/market value
- potential for use by more than one industrial sector (crosscutting potential)

The best metrics for measuring the efficacy of OIT research programs are likely to be some of the measures used internally by the IOF industries. R&D managers from these industries should be contacted and polled regarding their approaches to setting priorities and to measuring effectiveness. However, some "profit-based" metrics used by industry to assess the efficacy of R&D may not be appropriate for assessing government-funded research. Short-term commercial potential should not be used to direct the selection of OIT's programs.

Recommendation. OIT should develop and apply realistic metrics to provide credible assessments of the technical and commercial successes of OIT research. Metrics should include measures of energy use, waste generation, resource utilization, and economic impact. The bases of these metrics should be clear and transparent to avoid the perception of "metric inflation."

OVERALL ASSESSMENT

The committee believes that the IOF program, to date, has been a success. The principal tangible successes have been the creation of industry vision documents and technology road maps. Although the committee believes that the IOF strategy will make the OIT program more effective, it is too early to judge the effect of the IOF strategy on the effectiveness of DOE-sponsored research in terms of OIT's mission of reducing waste and energy consumption.

Recommendation. OIT should take the following steps to ensure that the momentum of establishing the IOF industry groups and the vision and road map processes is maintained:

- continuing to provide significant funding for research that addresses identified industry needs
- involving industry representatives in monitoring ongoing projects and evaluating planned IOF-specific and crosscutting projects.

Recommendation. OIT should continue to adhere closely to the philosophy of the IOF program (i.e., continue to work closely with industry and allow industry to guide the process and set priorities).

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Gary A. Baum is vice president of technology for the Institute of Paper Science and Technology. His research has focused on paper physics and mechanical properties, the electrical properties of polymers, and the processing of paper and paperboard. Dr. Baum had many years of experience in industrial processing with Dow Chemical, the Institute of Paper Chemistry, the James River Corporation, and North Carolina State University before moving to his current position.

John V. Busch is president and founder of IBIS Associates. His professional focus is in economics and business development for technology-based organizations with specialties in business development, cost modeling, and technology assessment. In addition to his business background and experience, Dr. Busch has technical background in materials science and engineering, industrial materials processing, polymers and composites, economic analysis, and cost modeling.

Norman A. Gjostein is a materials engineering consultant. He retired in 1995 as director of Powertrain and Materials Research Laboratory at Ford Motor Company. Dr. Gjostein's directorate included research in automotive materials, engines, computer-aided engineering, and manufacturing systems. His experience has included 35 years at Ford, mostly in the evaluation and application of advanced materials in automotive systems. He has experience in process design and commercialization, as well as in the evaluation of intermetallic alloys for automotive engine applications. Dr. Gjostein is a member of the National Academy of Engineering.

Francis C. McMichael is professor of civil engineering and public policy and Blenko Professor of Environmental Engineering at Carnegie-Mellon University. His research concerns the effects of industrial processing on ground-water quality, hydrology, applied statistics, risk analysis, and solid and hazardous waste management. He has a particular interest in process control, monitoring, and in-process recycling of process waste streams. Dr. McMichael is a recognized leader in industrial ecology and has been a consultant to the steel industry. He has served on the Science Advisory Board for the Environmental Protections Agency.

Maxine L. Savitz is general manager of AlliedSignal Ceramic Components. Her experience includes materials development, production, and utilization; technology transfer; energy policy and energy conservation; and aerospace technology. Dr. Savitz has served on research advisory panels concerned with materials and processing and energy programs for several agencies, including the Gas Research Institute, The National Institute of Standards and Technology, DOE, and the Oak Ridge National Laboratories. Dr. Savitz is a member of the National Academy of Engineering.