DOCUMENTED BRIEFING

Research Priorities of the Supporting Industries Program

Linking Industrial R&D Needs

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Prepared for the

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PREFACE

This documented briefing summarizes the results of an independent analysis of the vision statements and other documents relevant to the Industries of the Future initiative of the U.S. Department of Energy (DOE) Industrial Technologies (IT) program. The RAND Corporation analyzed this information to identify links between the DOE/IT Supporting Industries program and other DOE/IT programs, which could potentially form the basis for alliances to facilitate the achievement of research goals.

This briefing is a sequel to Silberglitt and Mitchell, *Industrial Materials for the Future (IMF) R&D Priorities,* RAND Corporation, DB-364-NREL (2001), which identified high-priority, multiple-industry materials research needs for the DOE/IT Industrial Materials for the Future program. In this briefing, the authors focus on both materials and materials processing research priorities of the Supporting Industries program. This briefing should be of interest to industrial research and development sponsors, managers, performers, and analysts, as well as executives and managers in the industries addressed by the DOE/IT programs.

This project was performed under the auspices of RAND Science and Technology (S&T) and was sponsored by the Supporting Industries program through a subcontract with Oak Ridge National Laboratory.

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SUMMARY

The U.S. Department of Energy Industrial Technologies (DOE/IT) program (formerly the Office of Industrial Technologies [OIT]) supports technology partnerships with energy-intensive industries interested in developing and adopting new technologies with the goal of improving industrial energy efficiency. To achieve this goal, DOE/IT has undertaken the Industries of the Future (IOF) initiative, through which industry-government teams develop vision statements and technical roadmaps that identify performance targets and research needs to achieve industry goals.[1] Nine industries—agriculture, aluminum, chemicals, forest products, glass, metal casting, mining, petroleum, and steel—are included in the IOF initiative.

In a previous study conducted for the DOE/IT Industrial Materials for the Future (IMF) program (Silberglitt and Mitchell, 2001), RAND reviewed every IOF technical roadmap and constructed matrices that link research projects funded by the DOE to the performance targets and research needs described in the roadmaps.[2] The RAND Corporation then used those matrices to identify the IOF industries' high-priority materials research needs and the IMF program's research and development (R&D) priorities that are aimed at meeting those needs.

This documented briefing describes the results of a subsequent RAND study, conducted for the DOE/IT Supporting Industries (SI) program.[3] This study supplements the earlier IMF study data on performance targets, research needs, and research projects for five Supporting Industries—advanced ceramics, forging, heat treating, powder metallurgy and particulate materials (PM^2), and welding and joining. This study was done to identify materials and materials processing research priorities for the SI program and to identify links between the SI program and other DOE/IT programs (the various types of links are defined later in this summary). These links serve to illustrate the research needs and

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[1]Through these "vision statements" and "roadmaps," IOF participants set goals for the future, determine technology priorities, and assess the progress of research and development in their industries. The statements and roadmaps are available at http://www.oit.doe.gov/industries.shtml (click on any of the nine industries listed under "Industries of the Future," and then click on "Vision and Roadmaps" on the industry page).

[2]Readers may wish to review Silberglitt and Mitchell (2001) for background on the multiple-industry research priorities approach.

[3]Supporting industries are those that provide enabling materials or processes for the IOF industries (e.g., ceramic materials, powder metals, or particulate materials used in IOF process equipment, heat treating, forging, or welding and joining). The SI industries play a key role in helping the IOF industries to reduce their energy use and increase their efficient use of energy.

challenges that the DOE/IT programs have in common. They also define those areas in which DOE/IT programs can leverage their funds by working together and the overarching research needs and basic research areas that are critical to achieving the goals of more than one industry.

DATABASE ON MULTIPLE-INDUSTRY RESEARCH NEEDS, CATEGORIES, PROJECTS, AND RESEARCH AREAS

To define the links between the SI program and other DOE/IT programs, RAND integrated information on performance targets, research needs, and research projects from the matrices in Silberglitt and Mitchell (2001) into a database, which in turn facilitated the creation of four entities discussed in this briefing:

- Multiple-Industry Research Needs (MIR*N*s): R&D needs that appear in more than one industry roadmap.
- MIR*N* Categories: Groups of related R&D needs that appear in different industry roadmaps. They are useful because they enable the examination of a whole set of needs for all industries in closely related areas of research.
- Multiple-Industry Research Projects (MIR*P*s): Projects that fulfill R&D needs in more than one industry roadmap.
- Multiple-Industry Research Areas (MIR*A*s): Underpinning[4] research areas that include MIRNs across multiple MIRN Categories.

This database contains all of the R&D needs and performance targets from the nine IOF industry roadmaps discussed in Silberglitt and Mitchell (2001)—i.e., all of the needs identified by the roadmap teams as being high priority (except in the case of the steel industry, for which the team did not identify priorities). As such, all of the steel materials-related needs are included in the database.

For this study, we added all of the R&D needs and performance targets from the five SI roadmaps to the database, resulting in 887 R&D needs and 133 performance targets.

The database also contains all of the DOE-funded projects (the matrix elements in Silberglitt and Mitchell [2001])[5] from sources referenced in that study[6] that address at

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[4]We describe MIRAs as "underpinnings" in this briefing because advances in those areas address basic needs that are common to multiple industries.

[5]For the Silberglitt and Mitchell study, a matrix with rows and columns consisting of performance targets and high-priority materials R&D needs, and matrix elements consisting of DOE research projects that address those targets and needs, was built for each of the nine IOFs. The matrices were used to identify multiple-industry research needs, projects that address those needs, and needs not currently addressed by projects.

least one of those R&D needs or performance targets. In addition, we included a group of priority projects recently proposed by the PM^2 industry roadmap team (*PM^2 Roadmap Collaboration Workshop*, 2003), leading to a total of 309 research projects.

Finally, we grouped similar R&D needs into categories and found that all the needs could be assigned to one or more of 25 MIRN Categories and that the following 14 MIRN Categories include research needs found in more than half of the 14 industry roadmaps:

- Databases and Properties (13 industry roadmaps)
- Standards Product Quality and Testing (13 industry roadmaps)
- Corrosion-, Erosion-, and Wear-Resistant Materials (12 industry roadmaps)
- Modeling and Simulation (12 industry roadmaps)
- Process Design and Improvement (12 industry roadmaps)
- Waste and Byproduct Treatment, Recycling, and Use (12 industry roadmaps)
- High-Temperature Materials and Refractories (11 industry roadmaps)
- Sensors and Sensor Materials (11 industry roadmaps)
- Design Tools (10 industry roadmaps)
- Process Monitoring and Control (9 industry roadmaps)
- Raw Materials (9 industry roadmaps)
- Coatings (8 industry roadmaps)
- Joining and Welding (8 industry roadmaps)
- Surfaces and Interfaces (8 industry roadmaps).

These MIRN Categories provide a good starting point to identify common research needs across industries that can be addressed through joint workshops, solicitations (i.e., requests for proposals for research projects), partnerships, and other coordinated activities between the DOE/IT programs and the industries they represent.

DATABASE ANALYSIS

Our analysis showed that the MIRN Categories, with one exception, include R&D needs from more than half of the five SI industries (i.e., at least three industries) *and* from more than half of the nine IOF industries (i.e., at least five industries). This illustrates the strong connection between the SI and IOF industries via the SI industries' role of providing materials and materials processing to create products and product components that reduce energy use and environmental impact and increase the productivity of the IOF industries. Moreover, within several multiple-industry research areas, two or more MIRN

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[6]Those sources included Energy Materials Coordinating Committee (fiscal year 1999), Materials Sciences Program (1998), and project descriptions listed on the OIT Web site.

Categories have a significant number of R&D needs in common. These links between MIRN Categories provide another indication of common research needs and can be used to identify the multiple-industry research areas.

Our analysis also showed that research projects funded or proposed by the SI program, in addition to those funded by the IMF program, typically address multiple research needs that are common to more than one industry roadmap and that fall into multiple MIRN Categories. By contrast, the projects funded by the IOF industry teams typically address a single research need that falls into a single MIRN Category. In fact, most of the SI and IMF projects are multiple-industry research projects that address multiple-industry research needs. A project that addresses the needs of multiple industries and that crosses the boundaries of multiple research areas is usually found within one of the underpinning MIRAs.

PROJECT LINKS AMONG SUPPORTING INDUSTRIES

Figure S.1[7] illustrates an example of how SI projects, industries with specific needs, and the MIRN Categories addressed by those projects are linked. The industries shown in the

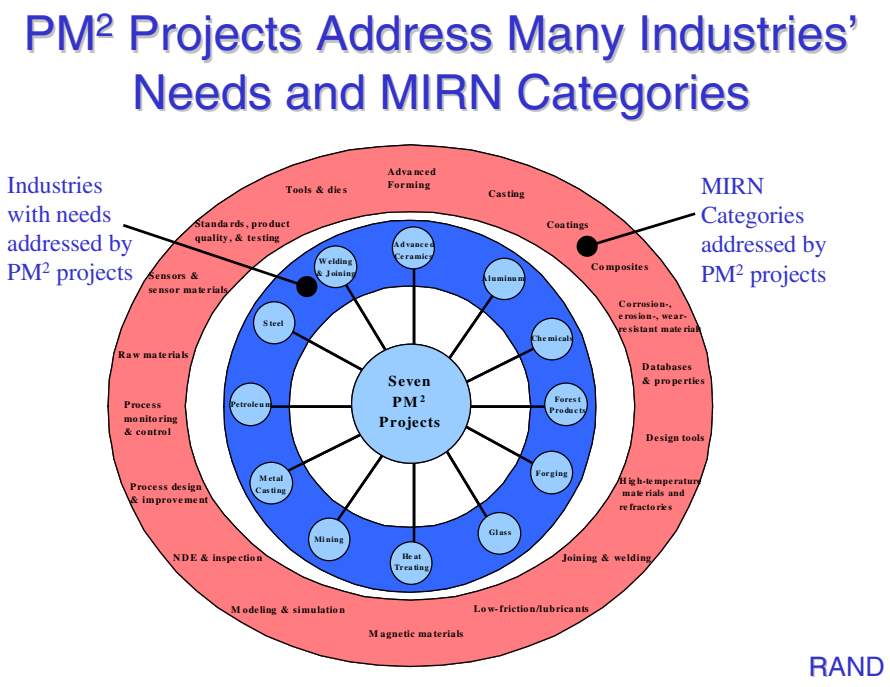

Figure S.1—How SI Projects Serve to Link Multiple Industries and MIRN Categories

[7]Readers wishing to see the figures in this briefing in greater detail may view them in the DB420slides.pdf file on the accompanying CD. The zoom tool may be used to increase the view size of the figures.

inner ring in the figure all have R&D needs addressed by one or more of seven priority projects proposed by the PM^2 industry roadmap team to meet PM^2 roadmap needs. The MIRN Categories shown in the outer ring are addressed by one or more of these same projects.

THE DATABASE NAVIGATOR

RAND developed a Microsoft PowerPoint presentation as a navigational tool to facilitate browsing through the database. This tool, which we call the "Database Navigator," or simply the "navigator," can be found on this document's accompanying CD. The database, which is in Microsoft Access format, is also included on the CD. The navigator, which is in HTML, is organized by MIRN Category pages, such as the example page for the MIRN Category "Adhesives" shown in Figure S.2.

The boxes on the right side of Figure S.2 list the three industries that have R&D needs within this MIRN Category. Each box links to a page that shows the R&D needs for that industry that fall within this MIRN Category.

The arrows on the left side of the figure illustrate the links to information on *other* MIRN Categories that apply to each industry. The width of the arrows denotes the number of industries the link encompasses. In this example, there are links for this MIRN Category to the Joining and Welding and to the Corrosion-, Erosion-, and Wear-Resistant Materials

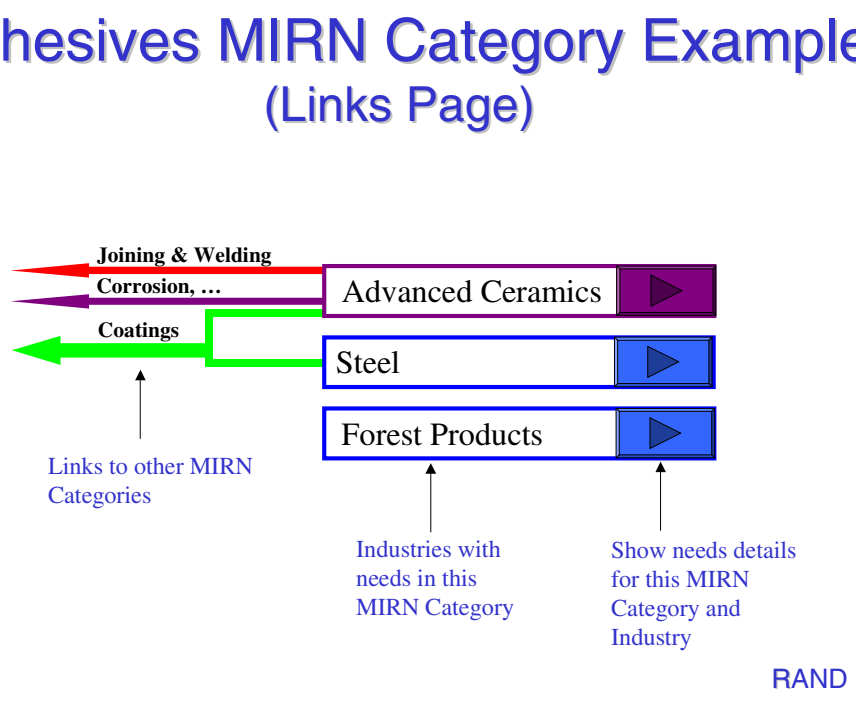

Figure S.2—Example Database Navigator Page for the MIRN Category "Adhesives"

MIRN Categories via R&D needs from the Advanced Ceramics industry roadmap. There are also links to the Coatings MIRN Category via R&D needs from the Advanced Ceramics and Steel roadmaps. The fact that no arrows emanate from the Forest Products box shows that although there are Adhesives R&D needs in the Forest Products roadmap, none of them fall into any other MIRN Category.

The pages with the needs details that are linked to this MIRN Category page by the arrows on the right side of the figure also link to additional pages that show all of the project information for all projects that address R&D needs in this MIRN Category for all industry roadmaps. Thus, the navigator can be used to browse through all industries and all MIRN Categories to identify research needs and research projects common to multiple industries.

IDENTIFYING MULTIPLE-INDUSTRY RESEARCH AREAS THROUGH LINKS ACROSS MULTIPLE-INDUSTRY RESEARCH NEEDS CATEGORIES

RAND used the navigator to analyze MIRN Category links across the 25 MIRN Categories, the five Supporting Industries, and the nine Industries of the Future. Browsing by MIRN Category showed consistent links among the Coatings; Corrosion-, Erosion-, and Wear-Resistant Materials; High-Temperature Materials and Refractories; and Tools and Dies MIRN Categories through the Advanced Ceramics, Forging, PM^2, Chemicals, Glass, Metal Casting, Petroleum, and Steel industries. We then concluded that the three SIs and five IOFs have strong overlapping research needs in coatings for resistance to severe environments.

Browsing by MIRN Category also identified links involving all five SIs and all IOFs, except Agriculture, between the Databases and Properties and Modeling and Simulation MIRN Categories. These MIRN Categories were further linked to Design Tools, Process Design and Improvement, Standards, Product Quality, and Testing, as well as to the Coatings-based MIRN Categories.

Finally, the navigator showed that Joining and Welding (which is both a MIRN Category and a Supporting Industry) is linked to 20 of the 24 other MIRN Categories through the Advanced Ceramics, PM^2, Aluminum, Chemicals, Forest Products, Metal Casting, and Steel industries. These common research needs represent opportunities for joint efforts between industries to maximize the impact of their R&D funds.

The MIRN Category links analysis also pointed the way toward the MIRAs that serve to underpin these common research areas. For example, the development and application of improved coatings for severe environments depend upon progress in the understanding and control of surface and interface properties of materials that have the ability to withstand these environments, e.g., materials such as ceramics for new refractories or metal alloys tailored for high-temperature oxidation or corrosion resistance. In addition, the design of materials for industrial process environments requires materials-property

databases and models that represent those environments with sufficient precision and reproducibility. Progress in solving the joining and welding problems identified in both SI and IOF roadmaps depends upon both of these MIRAs, i.e., understanding and controlling surfaces and interfaces, as well as accurate materials property databases and models.

CONCLUSIONS AND RECOMMENDATIONS

Our analysis of the SI and IOF roadmaps, and the DOE projects that address the R&D needs and performance targets described in these roadmaps, produced the following conclusions and recommendations.

Conclusions

- The R&D needs of the SI and IOF roadmaps are strongly linked through multiple common MIRN Categories.
- Most SI research projects address research needs in multiple industries, and are therefore MIRPs.
- The same MIRAs serve to underpin the achievement of both SI and IOF R&D needs.

Recommendations

- The DOE/Industrial Technologies programs should sponsor and participate in workshops that include multiple-industry teams and that cross the boundaries of multiple research areas. These "cross-cutting" workshops would differ in both participation and content from the roadmap workshops that these programs normally sponsor. Participants should include members of all industry teams with relevant R&D needs, plus guest speakers who are knowledgeable about ongoing and prospective research projects that could address those needs. The format should allow for industry presentations on their R&D needs, detailed technical presentations at the project level, and discussions between researchers and end users of the research, leading to the identification of priority research projects. The first of these workshops could address the common research areas: coatings for resistance to severe environments, databases and models for process design and quality control/standards, and joining and welding. The participating industries should at least be those that have roadmapped needs within the linked MIRN Categories that relate to these research areas, but invitations could also be extended to participants from other industries. Subsequent workshops would address other MIRAs, and the relevant industrial and research personnel for those areas and industries would be invited.

- The DOE/IT programs should coordinate their solicitations (i.e., requests for proposals) to allow for joint research projects, where appropriate, that would address common R&D needs. The workshops discussed in the previous paragraph could identify such opportunities. The multiple-industry research areas that serve to underpin the common research areas, and in which the needs of multiple industries cross the boundaries of multiple research areas, are another source of joint solicitation and joint research project opportunities.
- The DOE/IT staff should use the database RAND developed for this study to facilitate further discussion of links between DOE/IT programs. This dialogue could be initiated through discussions of MIRN and MIRN Category links and the relevant MIRPs by the program staff responsible for the industries that have the roadmapped needs being addressed and/or that are conducting projects addressing those needs. These discussions should be aimed at identifying common research needs and identifying underlying research problems that, if solved, would allow industries to meet those needs. Joint projects could then be funded to address those problems, after which each team would then separately fund projects aimed at their industry-specific needs. Through regular updating of the roadmaps and database, this process will continue to provide the means to identify and address research needs that industries have in common and opportunities for joint projects within common research areas.

ACKNOWLEDGMENTS

The authors express their appreciation to Ramesh Jain of the Department of Energy for his support and guidance during this study as well as for several useful and enlightening discussions. The authors are also grateful to Mike Soboroff and Charles Sorrell of the DOE for their willingness to provide data and comments during the performance of the study work and to Charles Sorrell for reviewing a draft version of this briefing.

Philip Antón of RAND provided the internal peer review, and the authors are extremely grateful for his detailed and insightful comments on both the illustrations and the text, which led to substantial revisions that clarified and amplified the technical discussion. Nancy DelFavero of RAND skillfully edited the final document to make the entire product significantly more precise and accessible to a wide range of readers. Thanks are also due to Clifford Grammich for several useful suggestions concerning definitions of MIRNs, MIRPs, and MIRAs.

ACRONYMS

BES	Basic Energy Sciences (Office of)
DOE	Department of Energy
EMaCC	Energy Materials Coordinating Committee
IMF	Industrial Materials for the Future
IOF	Industries of the Future
IT	Industrial Technologies
MIR*A*	Multiple-Industry Research Area
MIR*N*	Multiple-Industry Research Need
MIR*P*	Multiple-Industry Research Project
NDE	Non-destructive evaluation
NMAB	National Materials Advisory Board
NSF	National Science Foundation
ODS	Oxide Dispersion Strengthened
OIT	Office of Industrial Technologies
ONR	Office of Naval Research
OS	Office of Science
P/M	Powder metallurgy
PM^2	Powder metallurgy and particulate materials
R&D	Research and development
SI	Supporting Industries
S&T	Science and Technology
VT	Vision Team

INTRODUCTION

This documented briefing describes the results of a RAND Corporation study aimed at identifying links between the Supporting Industries (SI) program of the U.S. Department of Energy (DOE) Industrial Technologies (IT) program[1] and other DOE/IT programs. Such links can form the basis for alliances and partnerships that will facilitate the achievement of research goals. The scope of this project covers materials and materials processing research priorities.

In a previous study (Silberglitt and Mitchell, 2001), RAND created a set of matrices using the performance targets and research priorities of the nine energy-intensive industries in the DOE's Industries of the Future (IOF) initiative—agriculture, aluminum, chemicals, forest products, glass, metal casting, mining, petroleum, and steel. The performance goals and research priorities were drawn from industry "vision statements" and technical "roadmaps" created by industry teams.[2] RAND analyzed the matrices to determine which industrial materials research priorities would meet the needs of multiple industries. The study that is the subject of this briefing applied and expanded upon the matrix approach to include the research needs, performance targets, and research projects of five SI programs: advanced ceramics, forging, heat treating, powder metallurgy and particulate materials (PM^2), and welding and joining.[3]

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[1]Formerly known as the Office of Industrial Technologies (OIT).

[2]Through these vision statements and "roadmaps," IOF participants set goals for the future, determine technology priorities, and assess the progress of research and development in their industries. The statements and roadmaps are available at http://www.oit.doe.gov/industries.shtml (click on any of the nine industries listed under "Industries of the Future" and then click on "Vision and Roadmaps" on the industry page).

[3]The SI industries are those that provide enabling materials or processes for the IOF industries (e.g., ceramic materials, powder metals, or particulate materials used in IOF process equipment; heat treating; forging; or welding and joining). This briefing addresses five of the IT program's seven supporting industries.

Outline

- Project Objective and Role of SI Program
- Definitions of Analysis Elements and Links Between R&D Needs and Research Projects
- Database Characteristics and Analysis
- Powder Metallurgy and Particulate Materials (PM^2) Example
- Database Navigator
- Analysis of Multiple-Industry Research Need (MIRN) Category Links
- Conclusions and Recommendations

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This briefing is divided into seven sections. The initial section describes the project objective and the role of the SI program within DOE/IT. Next, we define the basic elements upon which our analysis is based—performance targets, research and development (R&D) needs, and research projects—as well as the various types of links between R&D needs and research projects. The third section explains the structure of the database that we compiled from those basic elements and the results of our analysis of this database. Next, we use the SI PM^2 program as an example to illustrate the different types of links. The fifth section describes a navigational tool (the "Database Navigator") that we developed to facilitate database browsing. After a brief exposition in the sixth section of the results of analyzing the links among a defined set of Multiple-Industry Research Need (MIRN) Categories (which are defined later in this briefing), we offer our conclusions and recommendations.

PROJECT OBJECTIVE AND ROLE OF THE SUPPORTING INDUSTRIES PROGRAM

Our objective in this study was to identify significant multiple-industry research challenges resulting from the research goals identified in the IOF and SI technical roadmaps. Meeting these challenges will require a coordinated effort by DOE/IT programs. With this in mind, our approach involved defining *links* between the SI programs and other IT programs at both the *research needs* and *research project* levels. We identified the links by creating and analyzing a database consisting of the research needs and performance targets from the IOF and SI technical roadmaps, together with the DOE-funded projects that address those needs and targets. The database includes all the elements of the nine IOF and five SI research-needs/performance-target matrices defined in a previous RAND study (Silberglitt and Mitchell, 2001), which analyzed the research needs of multiple IOF industries.[4]

[4]For the earlier study, a matrix with rows and columns consisting of performance targets and high-priority materials R&D needs, and matrix elements consisting of DOE research projects that address those targets and needs, was built for each of the nine IOFs. The

These links also illustrate the required exchange of knowledge between the programs, as well as the programs' common research needs and challenges. The links also define those areas in which DOE/IT programs can leverage their funds by working together on projects and the overarching research needs and research areas that are underpinnings critical to achieving the goals of more than one industry roadmap.

The analysis described in this briefing demonstrates the role of SI research in addressing the needs of multiple industries. The analysis also identifies opportunities for focusing solicitations and research projects to meet multiple-industry research challenges, and it highlights research areas that can provide the necessary advances to meet these challenges.

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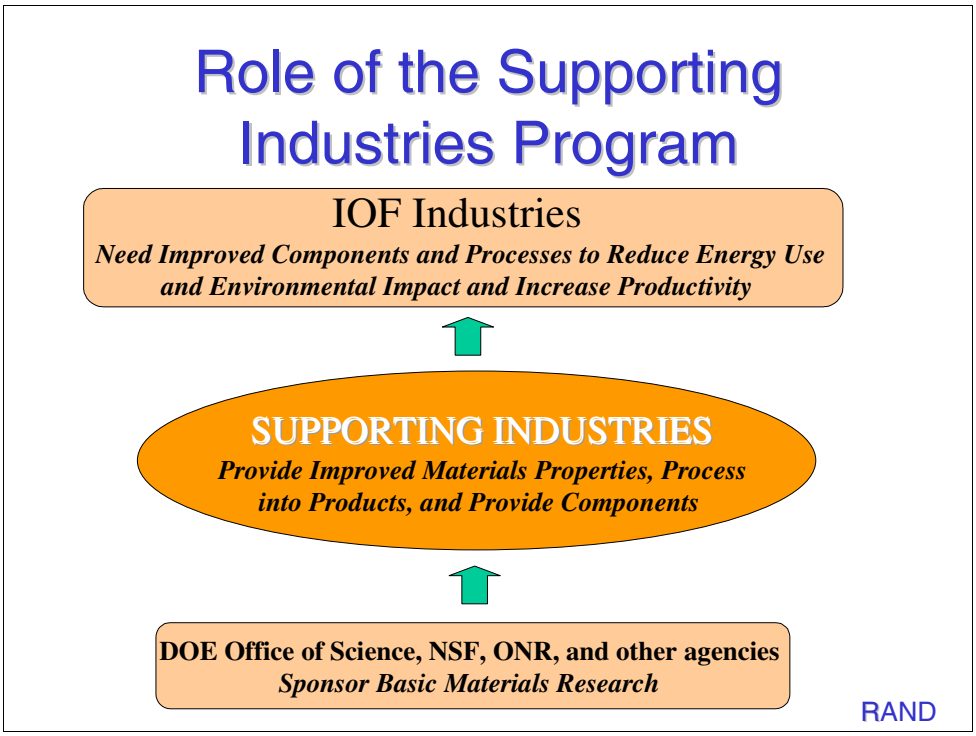
matrices were used to identify multiple-industry research needs, projects that address those needs, and needs that are not addressed by research projects.



The figure above illustrates the role of the Supporting Industries program, which conducts applied R&D that builds on results from the basic research programs of the DOE and other organizations. The SI R&D provides products and components that reduce energy use and environmental impact and increase the productivity of the IOF initiative industries.

The figure includes only the materials and materials-processing areas addressed in this study. Therefore, for purposes of this study, SI consists of programs that provide ceramic, particulate, and powder metallurgy materials with improved properties and that process those materials (and other advanced materials developed by the DOE's Industrial Materials for the Future [IMF] program) into products and components used by the IOF industries.

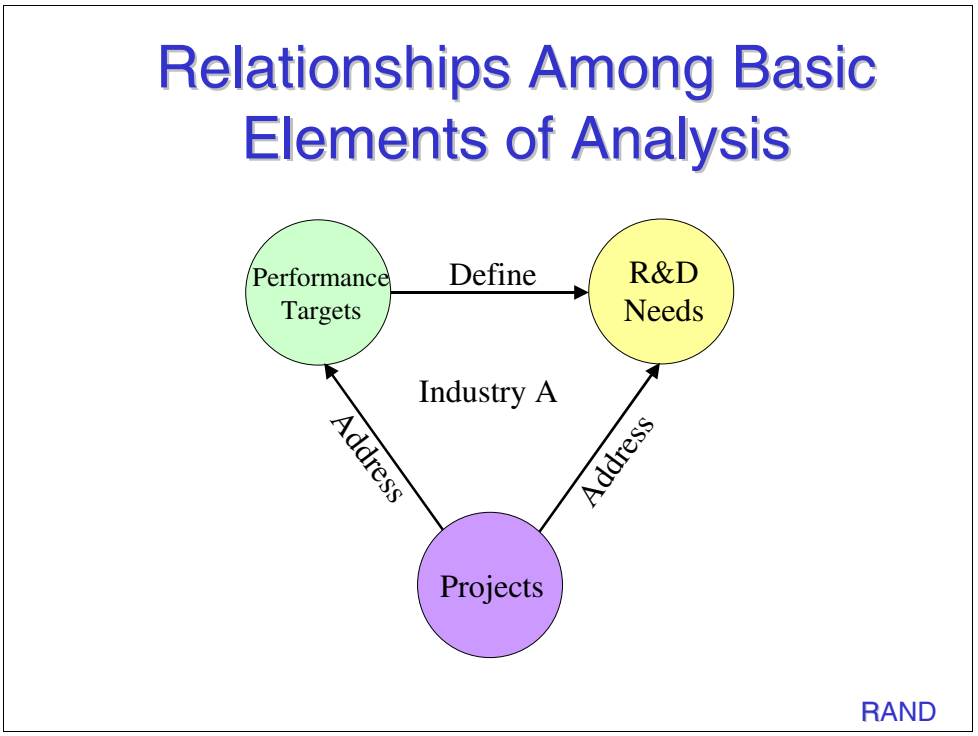
The SI research needs, as described in the SI program roadmaps, are both broad and challenging. They include research into corrosion, erosion, and wear resistance; high-temperature strength; composite materials; coatings; process-related needs such as advanced forming and tool-and-die materials; and the development of models, databases, simulation methods, and other design tools.

Our analysis of the research needs in the SI and IOF roadmaps, and the projects that meet those needs, demonstrates that in many if not most cases, research to meet SI needs also meets the needs of one or more IOF roadmap. For example, research on manufacturing of materials with nanoscale phases (identified as a priority by the PM^2 industry team) can be

a pathway to improved tool-and-die materials for aluminum, metal casting, and steel or corrosion- and wear-resistant materials for forest products and mining.

DEFINITION OF ANALYSIS ELEMENTS AND LINKS BETWEEN R&D NEEDS AND RESEARCH PROJECTS

In this section, we define the three basic elements that we used in this analysis (R&D needs, performance targets, and research projects), the sources of data for these elements, and the relationships among them. We also define the aggregated elements that were used to identify and describe SI links: Multiple-Industry Research Needs (MIR*N*s), MIRN *Categories*, Multiple-Industry Research Projects (MIR*P*s), and Multiple-Industry Research Areas (MIR*A*s).



Three basic elements were used in this analysis: R&D needs, performance targets, and DOE research projects.[5] The diagram above illustrates the relationships among these three basic elements. Performance targets or goals presented in the technical roadmaps serve to define the R&D needs for each of the Industries of the Future and Supporting Industries, and the research projects included in the analysis address these R&D needs and/or performance targets.

The diagram shows the relationships for an example industry, "Industry A." A diagram such as this can be created for each of the nine industries of the IOF initiative and for each of the five supporting industries addressed in this study.

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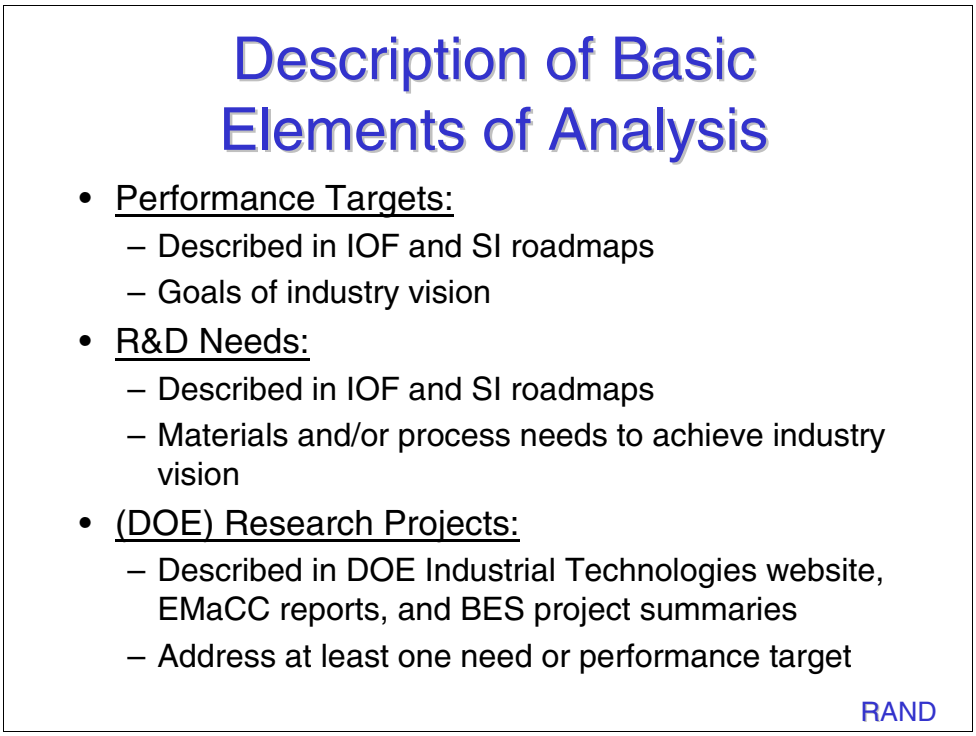
[5]These are the same basic elements used in Silberglitt and Mitchell (2001), in which R&D needs, performance targets, and research projects formed the rows, columns, and matrix elements of the performance-target/research-priority matrices.

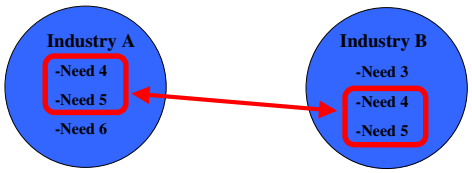


To develop descriptions of the basic elements for this analysis, we followed the same procedures used in Silberglitt and Mitchell (2001). The performance targets are as specified in the IOF and SI technical roadmaps and describe the goals defined by the IOF and SI industry teams to achieve the industry visions.[6] The R&D needs also are as specified in the IOF and SI technical roadmaps and describe materials or process R&D that is needed to achieve the industry visions defined by the IOF teams.

We used several sources to identify relevant DOE research projects: project summaries and descriptions of projects funded by DOE Industrial Technologies programs as listed on the DOE/IT Web site (http://www.oit.doe.gov); project summaries for DOE projects as listed in the Energy Materials Coordinating Committee (EMaCC) reports (e.g., Energy Materials Coordinating Committee, 2002); project summaries for materials research projects conducted by the DOE Office of Basic Energy Sciences (BES), as listed in the *Materials Sciences Programs* report (Materials Sciences Programs, 1998). To be included in our analysis, a research project had to address at least one R&D need or performance target specified in the IOF and SI technical roadmaps.

[6]The vision statements can be found at http://www.oit.doe.gov/industries.shtml.

Some R&D Needs Appear in More Than One Industry Roadmap



These needs are defined as Multiple-Industry Research Needs (MIRNs). In this example, Needs 4 and 5 are MIRNs because they appear in both Industry A and Industry B roadmaps.

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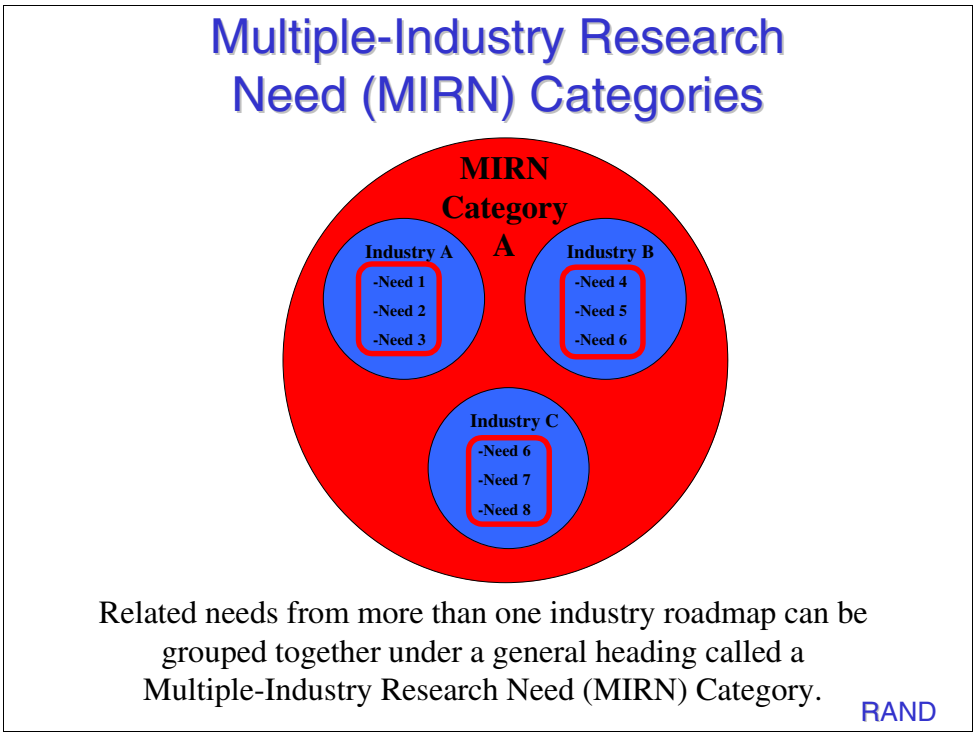
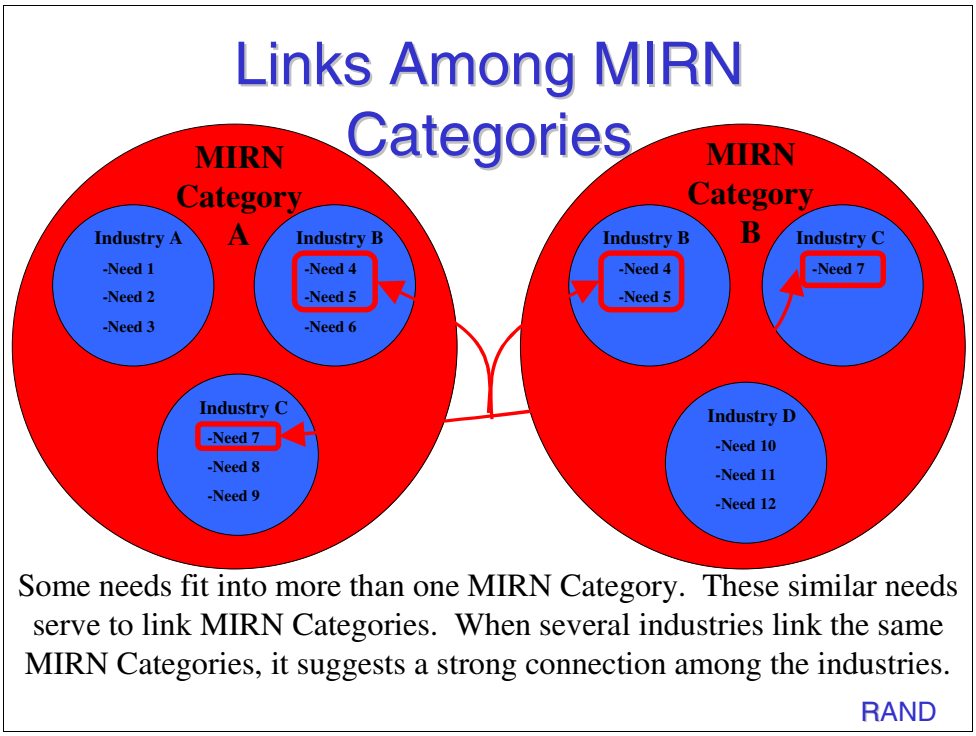
The industry roadmaps show that many industries have similar R&D needs. We define an identical R&D need appearing in more than one industry roadmap as a Multiple-Industry Research *Need* (MIR*N*).

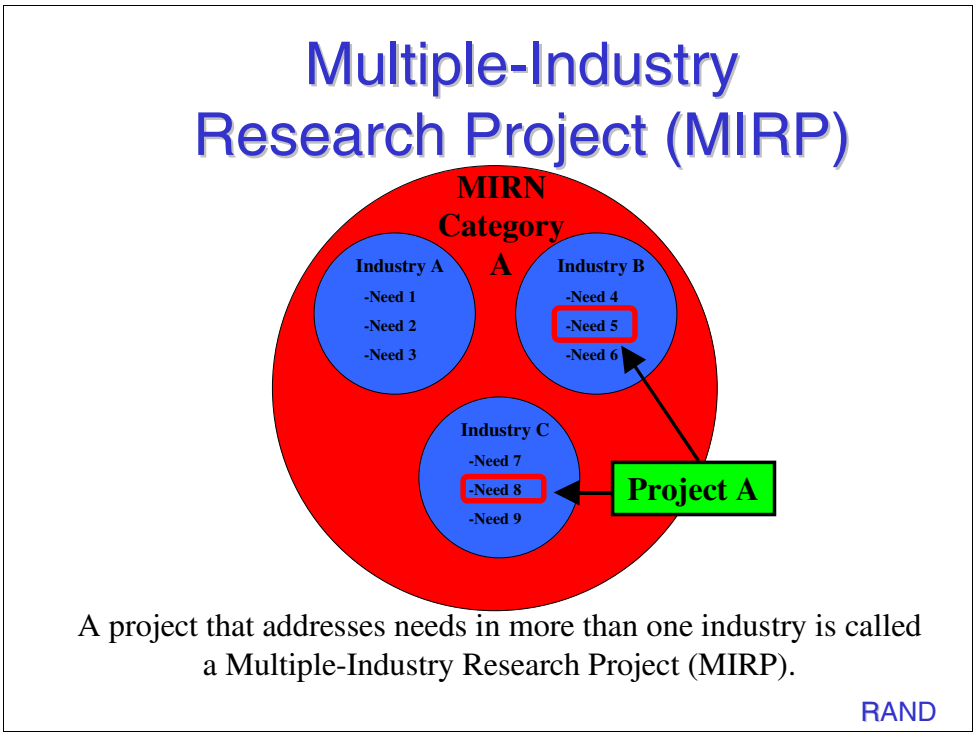


Analysis of the industry roadmaps shows that research needs can be grouped into categories, such as those mentioned previously for SI (e.g., coatings, composites, corrosion-resistant materials). We define category groupings that include research needs from more than one industry roadmap as Multiple-Industry Research Need *Categories*. Not all needs in a MIRN Category are MIRNs. For example, in the illustration above, Need 6 is a MIRN because it applies to Industry B and Industry C, but Needs 1–5 and Needs 7 and 8 are not MIRNs.

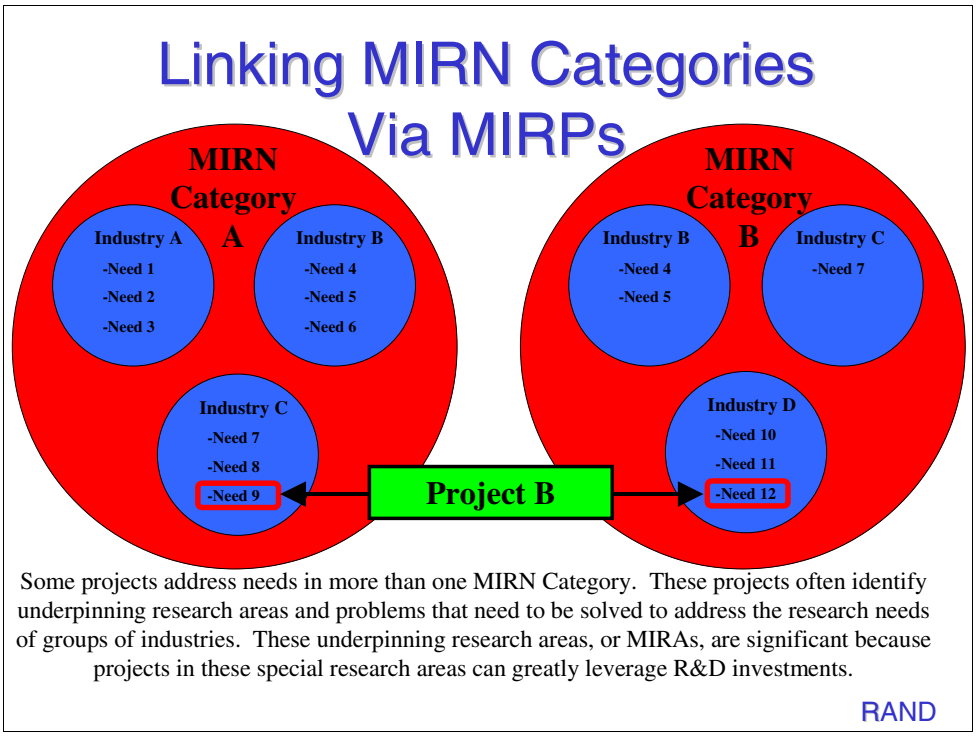
We found that the 25 MIRN Categories listed above describe all of the research needs in the nine IOF and five SI roadmaps analyzed in this study.



The assignment of needs to MIRN Categories was not exclusive—many research needs fit more than one MIRN Category. For example, the PM^2 need for "wear-resistant die materials or coatings" as defined by the industry roadmap fits the MIRN Categories "coatings," "corrosion-, erosion-, wear-resistant materials," and "tools and dies." Research needs that can be grouped across categories define broader linked research areas that are crucial to meeting the needs of multiple industries. We call these broader linked research areas Multiple-Industry Research *Areas,* or MIR*A*s.

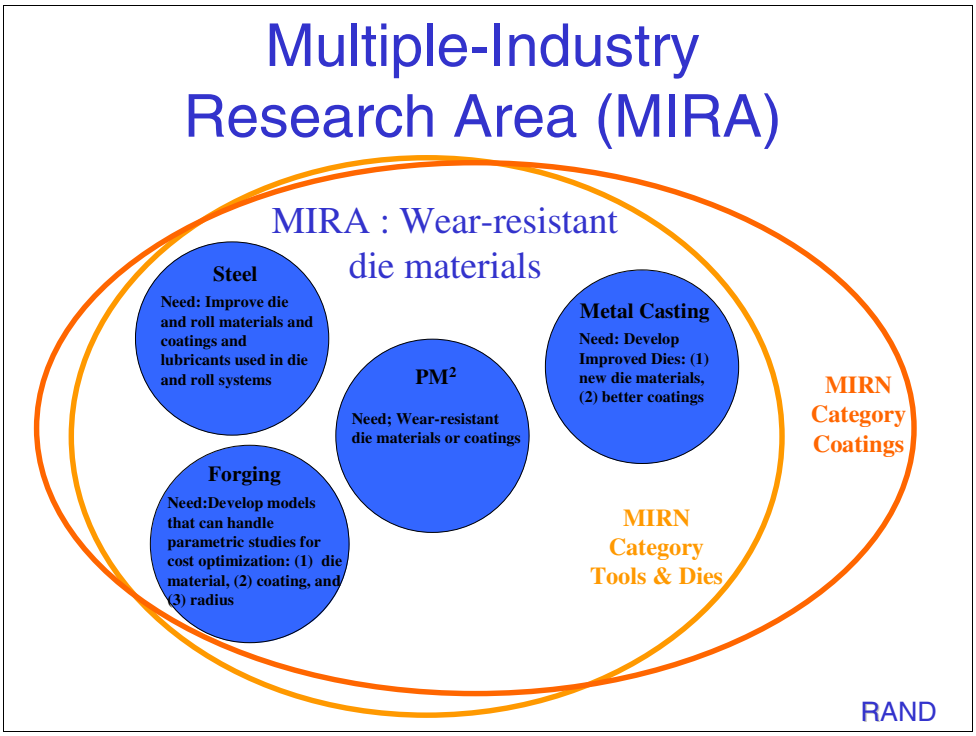


Some research projects address more than one research need. A research project that addresses needs in more than one industry is a Multiple-Industry Research *Project* (MIR*P*). MIRPs can provide a vehicle for addressing the needs of several industries in a cost-effective manner by solving common research problems that are impeding progress in related industry-specific areas.

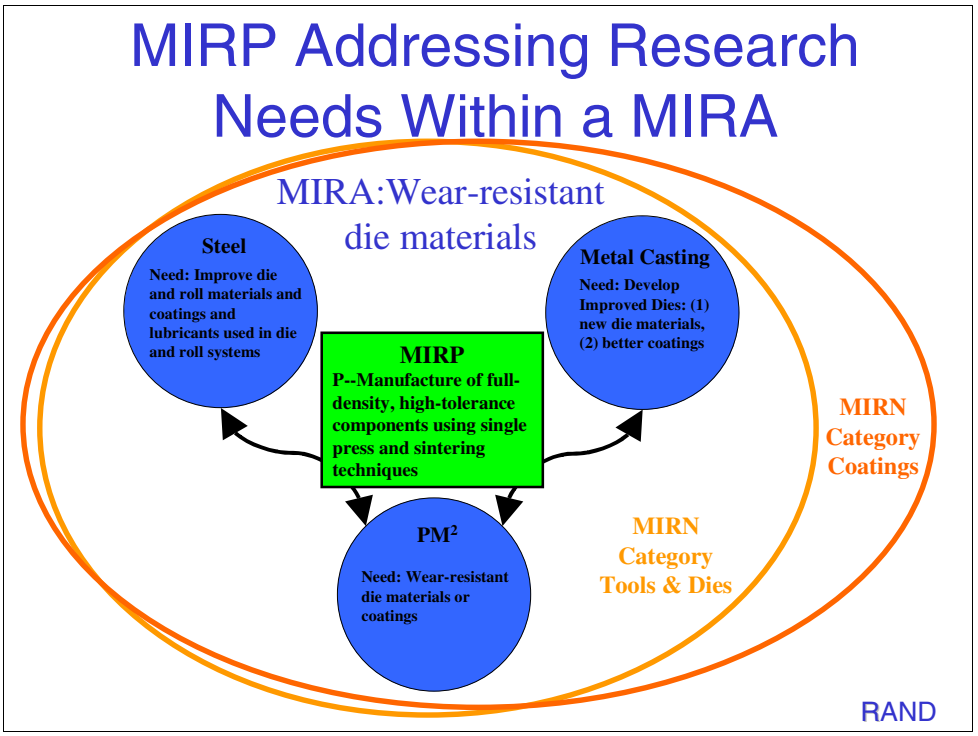


Some MIRPs are especially valuable in that they not only address the needs of more than one industry but also cross MIRN Categories.

MIRPs that link MIRN Categories often identify research areas that are underpinnings (i.e., MIRAs) and problems that, when they are addressed, can satisfy the research needs of groups of industries. MIRAs are significant because projects in these special research areas can meet the needs of more than one (and perhaps several) industries in disparate need categories. Consequently, they are areas in which R&D investments can be highly leveraged.



MIRAs can be identified not only by links between MIRN Categories created by MIRPs, but also by related research needs in different MIRN Categories. For example, the steel, forging, metal casting, and PM^2 industries all have research needs in the MIRN category of "tools and dies" and the MIRN category of "coatings." Research projects for developing or improving wear-resistant die materials, specifically projects for improving the properties of coatings or the processes for coating materials that can be applied to or used in tools and dies, are central to meeting the diverse needs of these four industries. Investment in this MIRA, in other words, can be leveraged to meet multiple needs in four different industries.



The illustration above shows a proposed project (denoted by the box in the center of the figure with "P" for "Proposed") that would address several research needs within the "wear-resistant die materials" MIRA illustrated on the previous page. By achieving full density in high-tolerance components that are pressed and sintered from powders that are tailored for toughness and chemical compatibility, this project could provide wear-resistant die materials and coatings for the steel and metal casting industries.[7]

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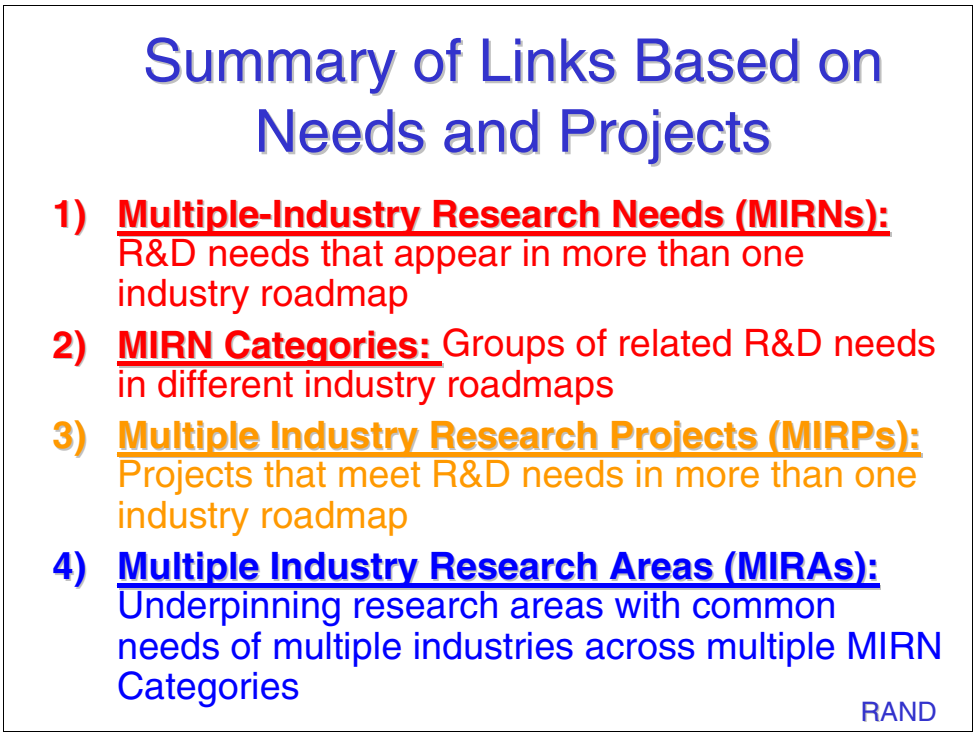
[7]Further analysis shows that this MIRP would also address needs in the advanced ceramics, aluminum, chemicals, forging, glass, and heat treating industries across the following MIRN Categories: advanced forming; casting; corrosion-, erosion-, and wear-resistant materials; high-temperature materials and refractories; low-friction/lubricants; and process design and improvement.

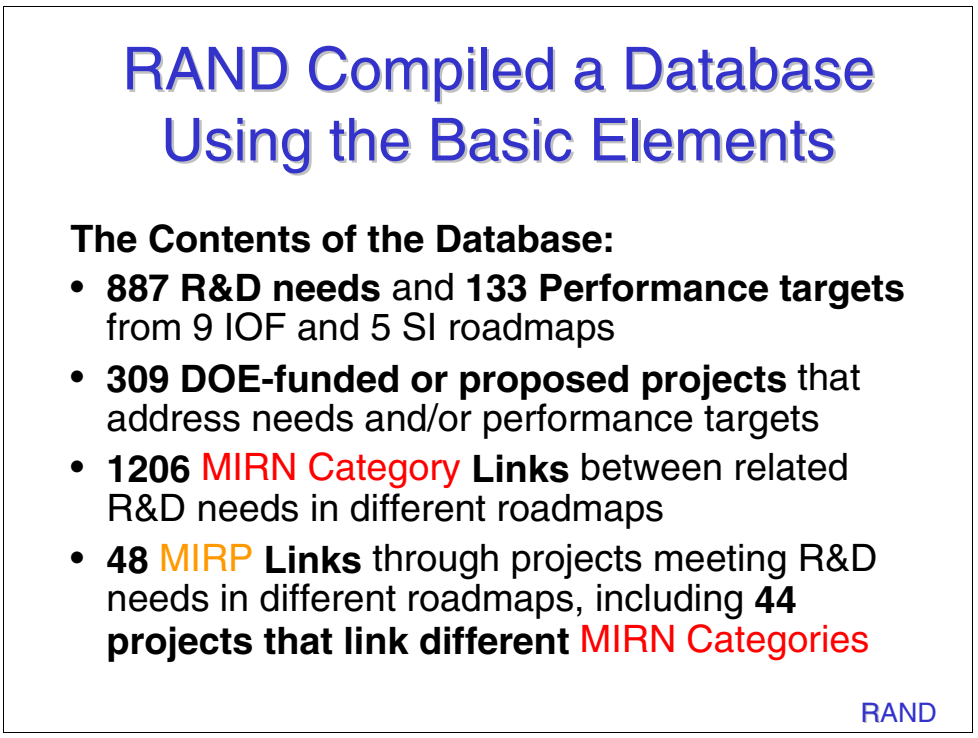


To recap, in this section we identified four distinct types of links based on the research needs and research projects of the Industries of the Future and Supporting Industries:

- *MIRNs* are R&D needs that appear in more than one industry roadmap.
- Related R&D needs, including MIRNs, can be grouped into *MIRN Categories.*
- *MIRPs* are research projects that meet R&D needs in more than one industry roadmap.
- *MIRAs*, sometimes identified through MIRPs that link MIRN Categories, occur when the needs of multiple industries cross the boundaries of multiple research areas. MIRAs are research areas that serve as underpinnings to provide new capabilities that multiple industries can use to meet their research challenges. For example, new powder metallurgy alloys with high hardness (wear resistance) are emerging as cost-effective tool-and-die materials for the steel industry and other industries (Carnes and Wert, 2001).

As noted previously, the SI program seeks to identify multiple-industry research areas that can be highly leveraged through the solving of problems that are impeding energy efficiency and productivity improvements in multiple industries. Opportunities for more focused research that benefits specific industries are being pursued by individual industry program teams, as outlined in their technical visions and roadmaps (see http://www.oit.doe.gov/industries.shtml).

DATABASE CHARACTERISTICS AND ANALYSIS



To facilitate the identification and analysis of the four types of linked elements discussed in the previous section—Multiple-Industry Research Needs, Multiple-Industry Research Need Categories, Multiple-Industry Research Projects, and Multiple-Industry Research Areas—RAND compiled a database of IOF and SI performance targets, needs, and research projects that constitute the elements of the industry performance-target/research-priority matrices defined in Silberglitt and Mitchell (2001). This section explains the structure of the database and describes the results of our analysis using the database.

This database contains all the R&D needs and performance targets from the nine IOF initiative industry roadmaps presented in Silberglitt and Mitchell (2001). These R&D needs include all the needs identified as being high priority by the teams of industry representatives who developed the industry roadmaps, except in the case of the steel industry, for which the roadmap team did not identify priorities; therefore, all materials-related needs for the steel industry were included in the database. For this project, RAND included in the database all the R&D needs and performance targets from the five SI roadmaps, leading to a total of 887 R&D needs and 133 performance targets.

The database created for this study also contains all of the DOE-funded projects (the matrix elements in Silberglitt and Mitchell [2001]) obtained from sources referenced in that study[8] that address at least one of these R&D needs or performance targets. In addition, we included in the database a group of priority projects recently proposed by the PM^2 industry roadmap team, giving us a total of 309 research projects.

With the 887 needs, 133 performance targets, and 309 projects, the database formed a combination of the nine IOF and five SI performance-target/research-priority matrices defined in Silberglitt and Mitchell (2001).

RAND then added to the database the following information on how the four elements are linked, which was obtained from an analysis of industry R&D needs and research projects.

- MIRN Category Links—We grouped similar R&D needs into categories and found that all needs could be assigned to one or more of the 25 MIRN Categories listed in the previous section of this briefing. The total number of links—i.e., the sum of the needs within each MIRN Category—was 1,206.
- MIRP Links—We also reviewed DOE-funded projects and identified those that addressed more than one research need in more than one industry. The number of these MIRPs totaled 48, including 44 that linked different MIRN Categories.

This additional linkage information allowed us to formulate queries and reports that provide a comprehensive description of the common research needs of the SI and IOF programs and the extent to which DOE research projects address common needs. This additional information also provided us with a means to analyze the relationships between MIRN Categories and the MIRPs that link those categories in order to identify MIRAs.

The remainder of this briefing describes the structure of the database, summarizes the results of the MIRN and MIRP links analysis, describes the procedure for identifying MIRAs, and presents our conclusions and recommendations on joint workshops and solicitations for DOE/IT programs to address areas of common need.

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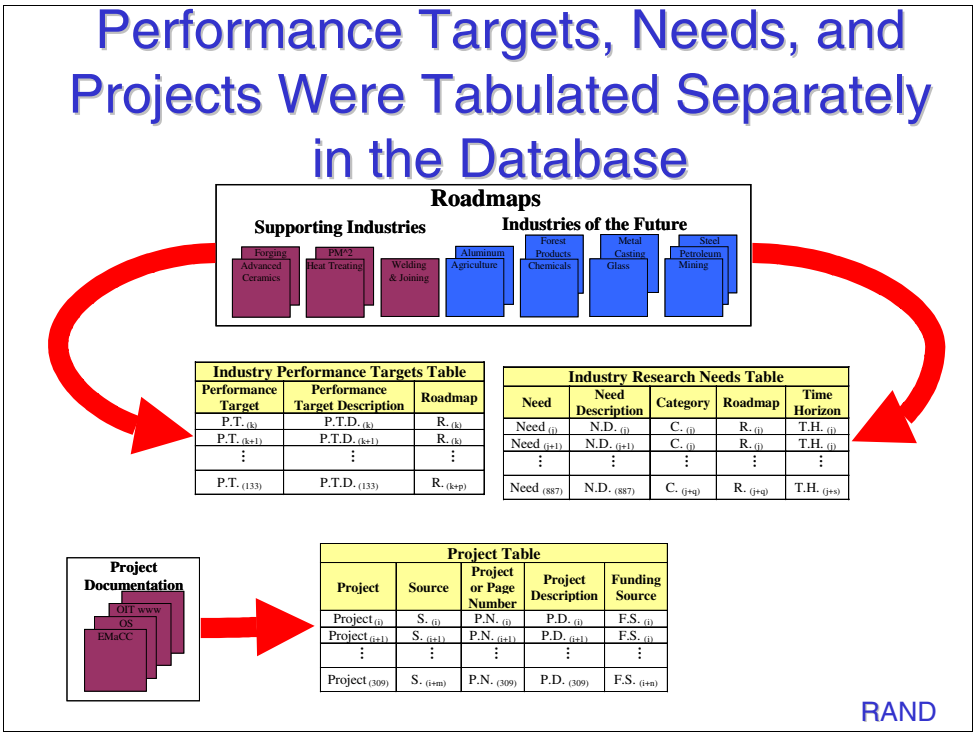
[8]Those sources included Energy Materials Coordinating Committee (fiscal year 1999), Materials Sciences Programs (1998), and project descriptions listed on the OIT Web site.

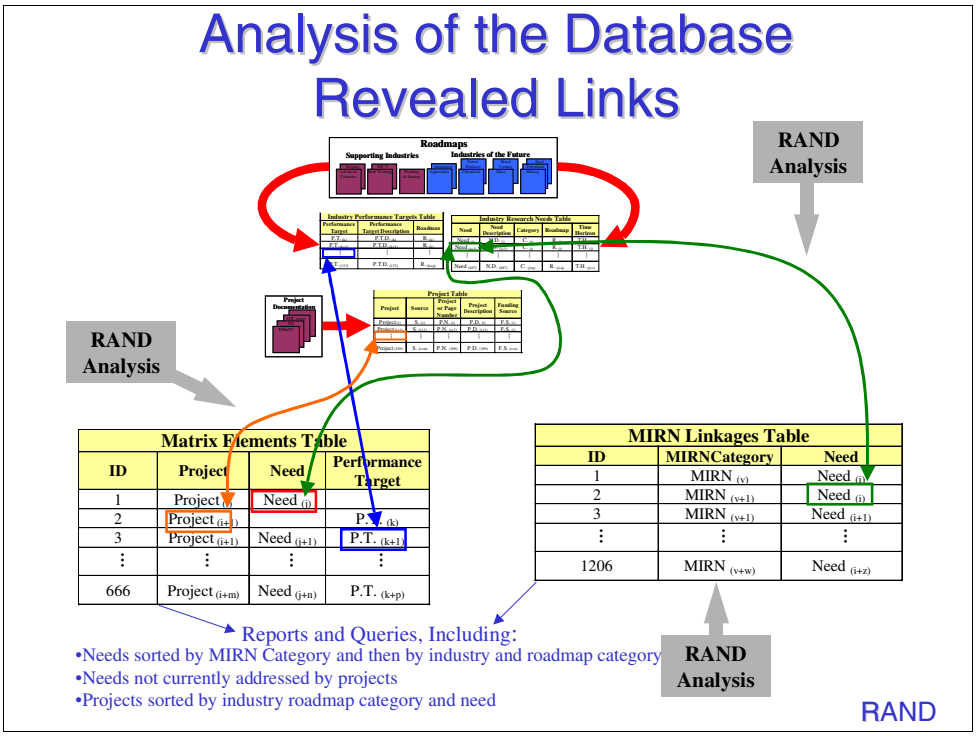


Using Microsoft Access, RAND developed a database of performance targets, R&D needs, projects, and links. The figure above schematically illustrates the structure of the database.

The data on the performance targets and R&D needs were taken from the nine Industries of the Future technical roadmaps and the five Supporting Industries technical roadmaps.[9] Using these data, we compiled a table of industry performance targets that lists the title and description of each performance target and the roadmap from which each was obtained. We compiled a similar table for each research need, categorizing each need according to a time horizon (e.g., near-term, mid-term, or long-term need) whenever that information was available from the roadmap.

The information on projects was obtained from project documentation on the DOE Industrial Technologies Web site, in Energy Materials Coordinating Committee (fiscal years 1994, 1996, 1997, and 1999) and in Materials Sciences Programs (1998). Using these data, we compiled a projects table that lists each project title, the source and location of the project data, an optional project description, and the funding source for each project.

[9]Available at http://www.oit.doe.gov/industries.shtml and http://www.oit.doe.gov/related/vision.shtml, respectively.



The figure above schematically illustrates the structure of the relationships among the elements in the database. In the tables representing the three basic elements in this analysis—performance targets, R&D needs, and projects—each element is listed once and each row of each table is unique. However, one-to-many relationships exist between the individual elements because the same project may address more than one need or performance target. In addition, as described previously, RAND grouped similar research needs from different roadmaps into MIRN Categories, and many of the needs fell within multiple MIRN Categories.

To represent these one-to-many relationships, we developed two tables. The first, a "Matrix Elements Table," lists every project meeting a specific need and/or performance target. In developing this table, RAND reviewed each of the 309 projects, scanned all of the 887 needs and 133 performance targets, and made technical judgments on whether or not a project addressed one or more needs or performance targets. Each row in this table, therefore, represents a single case of a match between a research project and a need or performance target and a single matrix element in the performance-target/research-priority matrices in Silberglitt and Mitchell (2001).

In performing this task, RAND used technical judgments concerning the relationships among projects, performance targets, and research needs from the Industries of the Future analysis in the 2001 study and added new technical judgments related to SI projects, performance targets, and research needs. Because many of the 309 projects meet

more than one need or performance target, there are 666 rows in the Matrix Elements Table.

The second table, the "MIRN Links Table," summarizes the results of RAND's analysis of the relationships between the 887 research needs taken from the five SI and nine IOF roadmaps. This table contains 1,206 rows because we assigned research needs to multiple MIRN Categories wherever appropriate.

These tables formed the basis for a series of reports and queries that we used to perform the analysis presented in the remainder of this briefing. Those reports include:

- Needs sorted first by MIRN Category and then by industry and roadmap category
- Needs not currently addressed by projects
- Projects sorted by industry roadmap category and need.

We also analyzed reports sorted alternatively by need, project, MIRN Category, and industry roadmap category to identify MIRN and MIRN Category links, MIRPs, MIRN Category links through MIRPs, and MIRAs, as described next.

Summary of MIRN Category Links

MIRN Category	# of Roadmaps	# of R&D Needs	MIRN Category	# of Roadmaps	# of R&D Needs	MIRN Category	# of Roadmaps	# of R&D Needs
1) Adhesives	3	5	10) Human and technical resources	5	33	**19) Raw materials**	**9**	**44**
2) Advanced forming	6	37	**11) Joining and welding**	**8**	**164**	**20) Sensors and Sensor materials**	**11**	**53**
3) Casting	3	13	12) Low-friction/Lubricants	5	10	21) Separation technologies	5	21
4) Coatings	**8**	**73**	13) Magnetic materials	2	2	**22) Standards, product quality, and testing**	**13**	**74**
5) Composites	3	43	14) Markets and applications	6	9			
6) Corrosion-, erosion-, wear-resistant materials	**12**	**44**	**15) Modeling and simulation**	**12**	**110**	**23) Surfaces and interfaces**	**8**	**16**
7) Databases and properties	**13**	**59**	16) NDE and inspection	7	38	24) Tools and dies	6	29
8) Design tools	**10**	**31**	**17) Process design and improvement**	**12**	**160**	**25) Waste and byproduct treatment, recycling, and use**	**12**	**50**
9) High-temperature materials and refractories	**11**	**43**	**18) Process monitoring and control**	**9**	**48**			

MIRN Categories in black cover more than half of the industry roadmaps

MIRN Categories in grey cover half or less than half of the industry roadmaps

RAND

The table above summarizes the results of the analysis leading to the identification of MIRN Category links. For each of the 25 MIRN Categories, the table shows both the total number of R&D needs and the number of industry roadmaps that encompass these needs.

The number of R&D needs in a MIRN Category ranges from 2 in Magnetic Materials to 164 in Joining and Welding, while the number of industry roadmaps that include R&D needs in each MIRN Category ranges from 2 in Magnetic Materials to 13 in Databases and Properties and Standards, Product Quality, and Testing. The following MIRN Categories include research needs in more than half of the 14 IOF and SI industry roadmaps examined for this study:

Databases and Properties—13 roadmaps

Standards, Product Quality, and Testing—13 roadmaps

Corrosion-, Erosion-, and Wear-Resistant Materials—12 roadmaps

Modeling and Simulation—12 roadmaps

Process Design and Improvement—12 roadmaps

Waste and By-product Treatment, Recycling, and Use—12 roadmaps

High-Temperature Materials and Refractories—11 roadmaps

Sensors and Sensor Materials—11 roadmaps

Design Tools—10 roadmaps

Process Monitoring and Control—9 roadmaps

Raw Materials—9 roadmaps

Coatings—8 roadmaps

Joining and Welding—8 roadmaps

Surfaces and Interfaces—8 roadmaps.

The 14 MIRN Categories that include research needs in more than half of the SI and IOF industry roadmaps share certain similarities. Some deal with specific types of materials (e.g., corrosion-resistant, high-temperature, sensor, or raw materials). Some deal with specific materials processing and interaction issues (e.g., coatings, joining and welding, surfaces and interfaces). Some deal with the development and use of basic materials and industrial process tools (e.g., databases and properties, modeling and simulation, design tools). Finally, some MIRN Categories deal with the industrial processes themselves (e.g., process design and improvement; process monitoring and control; standards, product quality, and testing; and waste and by-product treatment, recycling, and use).

These MIRN Categories provide a good starting point to identify common research needs that could be addressed through joint workshops, solicitations, partnerships, and other coordinated activities between the DOE/IT programs and the industries that they represent. Such efforts could be centered on desirable suites of properties indicated by the first group of MIRN Categories listed in the previous paragraph, which would include the research needs of all of the SI and IOF industries, or on the surface and interface-related processing issues represented by the second group of MIRN Categories listed above, which would include the research needs of all of the SI industries except Heat Treating and all of the IOF industries except Agriculture. The basic tools, such as databases, models, and design tools, constitute another area for a fertile collaborative effort that could potentially include all of the SI and IOF industries. The initial focus of this effort would be on data, model, and design tool development of generic interest to

multiple industries, which could enable more focused projects sponsored by individual programs or industries.

The MIRN Categories that deal directly with industrial processes include two different types of research areas. The first type involves primarily research needs that are specific to the industrial process (e.g., development of a high-capacity aluminum furnace design). Useful collaborations between the industrial roadmap teams cannot easily be defined in this type of research area. The second type of research area is one in which process issues exist that span related industries; in this case, useful joint efforts can be defined. Powder metallurgy, metal casting, aluminum, and steel, collectively, and chemicals, petroleum, and forest products, collectively, are examples of two groups of industries with common process issues.

The Same MIRN Categories That Encompass Many IOFs Also Encompass Many SIs

(SI Research Provides Materials for IOF Products/Components)

MIRN Categories	Percent of R&D needs in each industry across MIRN Categories	Supporting Industries: Advanced Ceramics	Forging	Heat Treating	PM^2	Welding & Joining	Industries Of The Future: Agriculture	Aluminum	Chemicals	Forest Products	Glass	Metal Casting	Mining	Petroleum	Steel
	Adhesives	1.6%								2.6%					3.3%
	Advanced forming	6.0%	2.6%		15.7%	2.0%		4.4%				3.7%			
	Casting							17.4%				18.5%			13.3%
	Coatings	30.4%	4.4%		0.9%				3.0%		3.2%	7.4%		2.8%	20.0%
	Composites	20.7%			3.7%	0.7%									
	Corosion-, erosion-, wear-resistant materials	8.2%	2.6%	1.9%	1.9%	1.3%		4.4%	33.3%	2.6%	3.2%		10.0%	5.6%	6.7%
	Databases and properties	7.1%	4.4%	1.9%	9.3%	2.7%	35.7%	26.1%	6.1%	5.1%	3.2%	7.4%	6.7%		3.3%
	Design tools	6.5%	1.7%		2.8%	4.0%	3.6%	3.5%		2.6%		11.1%	3.3%	2.8%	
	High-temperature materials and refractories	4.9%	2.6%	7.4%	3.7%	2.0%		4.4%	9.1%		19.4%	3.7%		2.8%	26.7%
	Human and technical resources		7.0%		11.1%	6.7%			3.0%			7.4%			
	Joining and welding	3.8%			0.9%	100.0%		4.4%	6.1%	2.6%		3.7%			3.3%
	Low-friction/lubricants	1.1%	2.6%		2.8%						3.2%				3.3%
	Magnetic materials				0.9%	0.7%									
	Markets and applications	0.5%			2.8%	0.7%	7.1%			2.6%		3.7%			
	Modeling and simulation	8.7%	24.4%	24.1%	7.4%	12.7%		13.0%	21.2%	7.7%	12.9%	3.7%	13.3%	11.1%	
	NDE and inspection	4.9%	6.1%			8.0%		4.4%	12.1%			3.7%		11.1%	
	Process design and improvement	19.0%	15.7%	38.9%	2.8%	20.7%	39.3%	30.4%		10.3%	16.1%		33.3%	25.0%	20.0%
	Process monitoring and control	3.8%	9.6%	5.6%		12.7%					3.2%	3.7%	3.3%	11.1%	3.3%
	Raw materials	6.0%	1.7%	3.7%	7.4%	4.0%	7.1%			28.2%		3.7%			3.3%
	Sensors and sensor materials	2.2%	4.4%	9.3%	8.3%	10.0%		8.7%	3.0%	2.6%	22.6%	7.4%	6.7%		
	Separation technologies						3.6%			5.1%	3.2%		46.7%	8.3%	
	Standards, product quality, testing	12.0%	7.8%	1.9%	12.0%	9.3%	3.6%	17.4%	6.1%	2.6%	9.7%	7.4%	3.3%	2.8%	
	Surfaces and interfaces		2.6%		1.9%	1.3%		13.0%		2.6%	3.2%		6.7%		6.7%
	Tools and dies	0.5%	14.8%		3.7%			8.7%				11.1%			6.7%
	Waste and by-product treatment recycling and use	1.1%	2.6%	11.1%	3.7%	2.7%		4.4%		30.8%	6.5%	7.4%	13.3%	16.7%	13.3%

Key: 0 | 0 < X < 10 | 10 = X < 20 | 20 = X

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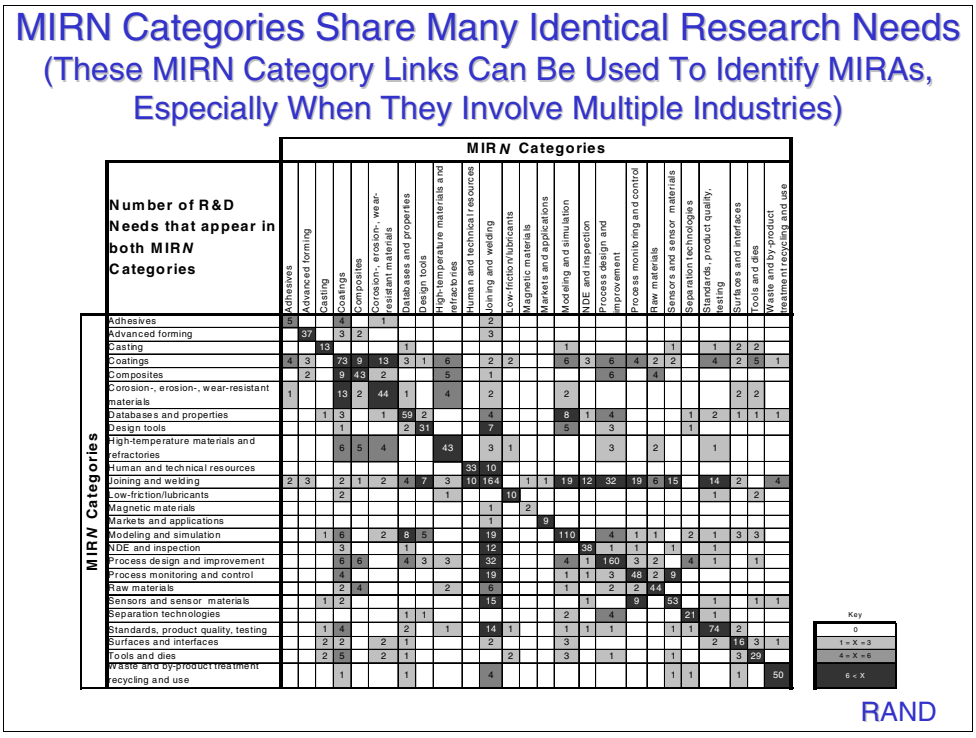
The table above summarizes the distribution of R&D needs in the 25 MIRN Categories throughout the SI and IOF industries. The MIRN Categories are listed in the far-left column and the Supporting Industries and Industries of the Future appear in the column headings. Each entry in the table cells is the percentage of the total R&D needs of the particular industry that intersects with a particular MIRN Category. (The numbers do not add up to 100 per cent in each column because R&D needs have been assigned to multiple MIRN Categories where appropriate, as described previously.) As indicated next to the lower right-hand corner of the table, the darker the shading in the table cells, the higher the percentage of industry R&D needs that fall within a category.

This table shows that the MIRN Categories that include R&D needs from more than half of the SI and IOF industries collectively (a total of at least eight industries between the two) also include R&D needs from more than half of the SI industries (at least three) *and* more than half of the IOF industries (at least five), with one exception. The Raw Materials category includes all five of the SI industries, but only four of the nine IOF industries. This illustrates the strong connection between the SI and IOF industries via the SI role of providing the materials and materials processing needed to create products and components that reduce the energy use and environmental impact and increase the productivity of the IOF initiative industries.



As noted previously, some R&D needs fall into more than one MIRN Category. For example, the chemical industry need "improved thermal spray coatings resistant to liquid corrosive environments" falls into both the Coatings and the Corrosion-, Erosion-, and Wear-Resistant Materials categories. Needs that fall within multiple MIRN Categories provide links between those MIRN Categories. The table above summarizes the distribution of multiple MIRN Category R&D needs (i.e., MIRN Category links). MIRN Categories are listed both in the far-left column and in the column headings, and the table cells show the number of industry roadmap R&D needs that fall within *both* MIRN Categories that intersect at each cell. As indicated next to the lower right-hand corner of the slide, the darker the shading in a table cell, the higher the number of R&D needs that fall within both the intersecting categories. We note that the higher numbers for Joining and Welding, as compared with the other categories, resulted from Joining and Welding being both a Supporting Industry and a MIRN Category.

The table above also illustrates several areas in which two or more MIRN Categories have a significant number of common R&D needs, e.g., Coatings; Corrosion-, Erosion-, and Wear-Resistant Materials; High-Temperature Materials and Refractories; Modeling and Simulation, and Process Design and Improvement. These MIRN Category links provide another indication of common research needs and can be used to identify MIRAs, especially when they involve multiple industries.

Several DOE Programs Fund Projects That Address IOF Needs

(The SI and IMF Programs Address Many IOF Needs Per Project)

	Sum over all projects funded by each source of the needs addressed by each project	Project Funding Source: IOF	SI	IMF	OIT Financial Assistance Program	OS	Total
Industries Of The Future	Agriculture	16		1		2	19
	Aluminum	19	12	7	6	15	59
	Chemicals	7	6	12	5	19	49
	Forest Products	53	3	17	6	3	82
	Glass	6	5	37	16	7	71
	Metal Casting	13	7	10	5	3	38
	Mining	4	1	4	3	18	30
	Petroleum	1	2	2	7	11	23
	Steel	40	8	18	5	12	83
	IOF Subtotal	**159**	**44**	**108**	**53**	**90**	**454**
Supporting Industries	Advanced Ceramics	4	8	*	1	*	13
	Forging	2	11	*	2	*	15
	Heat Treating		10	*		*	10
	PM^2	12	24	7	6	19	68
	Welding & Joining		10	*		*	10
	SI Subtotal	**18**	**63**	**7**	**9**	**19**	**116**
Grand Total		**177**	**107**	**115**	**62**	**109**	**570**
	Total # of Projects	**169**	**12**	**17**	**25**	**80**	**303**
	Average # of Needs Addressed per Project	**1.05**	**8.92**	**6.76**	**2.48**	**1.36**	**1.88**

* Note: RAND did not review projects funded by these sources with respect to these SI needs.

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The table above summarizes the funding sources of the materials and materials processing research projects included in this study. The matrix includes the SI and IOF industries and the DOE funding sources of these projects: an IOF Vision Team (VT), the Supporting Industries program, the Industrial Materials for the Future program, the OIT Financial Assistance program (now part of the DOE Weatherization and Intergovernmental Grants program), and the DOE Office of Science (OS). The numerical elements of the matrix are the sums (over all projects sponsored by a funding source) of the R&D needs of an industry addressed by each project.

As indicated in the Grand Total row and in the summary information below the table, the data illustrate the relatively small number of SI projects (even taking into account that SI represents five industries while IOF represents nine) versus the relatively large impact of SI projects in addressing the needs of the IOF industries. On average, the projects sponsored by the IOF initiative programs address slightly more than one R&D need, reflecting the single-industry focus of these programs. By contrast, the SI projects, on average, address nine R&D needs, and more than 40 percent of those needs are in the IOF industry roadmaps. This finding suggests that the SI program funds mostly multiple-industry research projects, and it further illustrates the links between the SI and IOF programs. The table shows that a similar situation exists for the IMF program. IMF projects, on average, address seven R&D needs, most of which are in IOF industry roadmaps. The average number of needs addressed by IMF projects is no doubt even larger than that because we analyzed whether IMF projects address needs in only one of the five Supporting Industries.

The SI and IMF Programs Are Strong Sources of Project-MIRN Category Links

(For Projects Involving Multiple Industries (MIRPs), These Links Can Also Identify MIRAs)

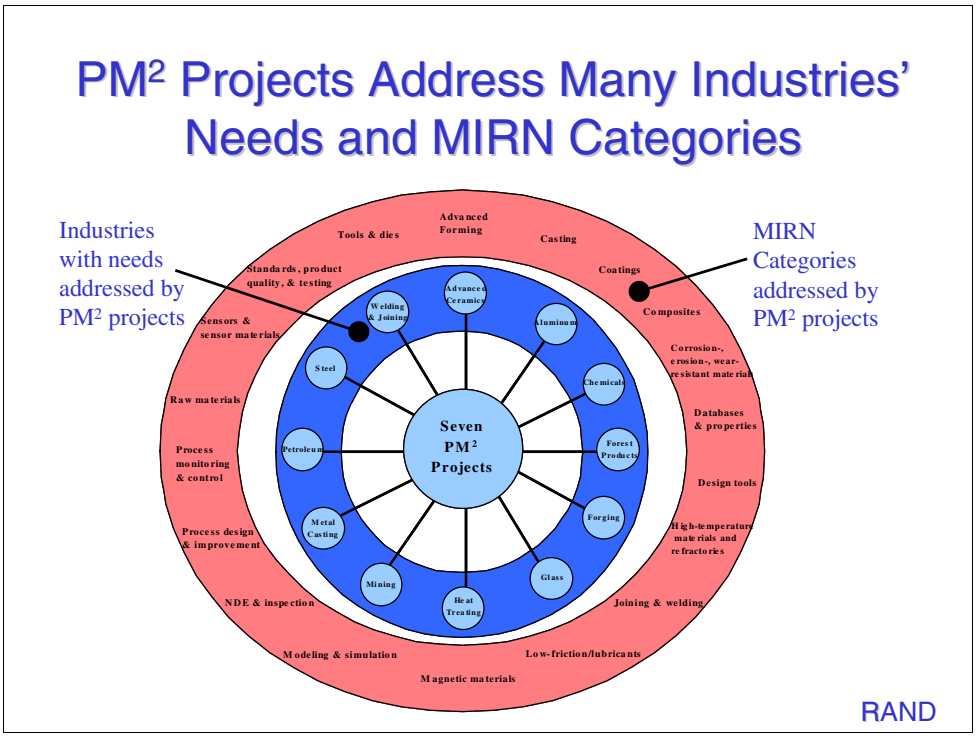
Funding Source	# of Industries in which Projects Address Needs	# of Projects	# of Projects Addressing 2 or more MIRN Categories		# of Projects Addressing 3 or more MIRN Categories		# of Projects Addressing 4 or more MIRN Categories		# of Projects Addressing 5 or more MIRN Categories		# of Projects Addressing 6 or more MIRN Categories		# of Projects Addressing 10 or more MIRN Categories	
IOF	12	169	26	15.38%	8	4.73%	6	3.55%	4	2.37%		0.00%		0.00%
SI	13	12	10	83.33%	10	83.33%	9	75.00%	5	41.67%	3	25.00%	1	8.33%
IMF	10	17	14	82.35%	8	47.06%	8	47.06%	7	41.18%	5	29.41%	2	11.76%
OIT Financial Assistance Program	11	25	10	40.00%	7	28.00%	3	12.00%	3	12.00%	2	8.00%		0.00%
OS	10	80	28	35.00%	18	22.50%	7	8.75%	2	2.50%	1	1.25%		0.00%
Grand Total		**303**	**88**	**29.04%**	**51**	**16.83%**	**33**	**10.89%**	**21**	**6.93%**	**11**	**3.63%**	**3**	**0.99%**

RAND

As we have discussed, some MIRN Categories are linked by projects. The table above summarizes these project/MIRN Category links. It shows that both the SI and IMF programs are strong sources of such links, in that more than 80 percent of those programs' projects link two or more MIRN Categories. By contrast, about 85 percent of the projects sponsored by the IOF initiative programs address R&D needs in only one MIRN Category.

The SI and IMF projects create multiple links among MIRN Categories, connecting up to ten MIRN Categories, with more than half of the SI projects and slightly less than half of the IMF projects addressing R&D needs that fall into at least four MIRN Categories. Most of the SI and IMF projects are MIRPs that link MIRNs; they address the needs of multiple industries across the boundaries of multiple research areas. Such projects typically fall within MIRAs.

POWDER METALLURGY AND PARTICULATE MATERIALS EXAMPLE



The figure above uses the Powder Metallurgy and Particulate Materials SI program to illustrate how the SI projects link groups of IOF industries through research that cuts across several MIRN Categories. The industries shown in the inner ring and connected by radial lines to the circle labeled "Seven PM^2 Projects" all have R&D needs addressed by one or more of the seven priority projects recently proposed by the PM^2 industry roadmap team to meet PM^2 roadmap needs. The MIRN Categories shown in the outer ring are addressed by one or more of the same seven projects.

The seven PM^2 priority research projects are listed next (throughout this section, the names of the projects are preceded by the letter "P" for "proposed"). The figures on the following pages show the MIRN Categories, industry roadmaps (either SI program or IOF Vision Team roadmaps), and the R&D needs addressed by each of these projects.

P–Advanced material manufacture using novel nanophase materials

P–Development of predictive tools for compression of time to describe properties (performance) at the component level (math-based component design, processing, and validation)

P–Development of sensor-based feedback control techniques to reduce process variation

P–Electromagnetic circuit design with three-dimensional powder metallurgy (P/M) magnets and core components

P–Joining of P/M components for greater functionality

P–Manufacture of full-density, high-tolerance components using single press and sintering techniques

P–Three-dimensional forming techniques for complex shapes.

P--Advanced material manufacture using novel nanophase materials (Part I of II)
(This project links 10 MIRN Categories, 4 SI and 8 IOF industries)

MIRN Category	Roadmap	Need
Advanced forming	Advanced Ceramics (SI)	Expand functionally gradient materials component fabrication R&D; consider bulk and surface gradation
Casting	Aluminum (VT)	Develop better tool and die materials with improved heat extraction capabilities (NMAB)
Coatings	Metal Casting (NMAB)	Develop Improved Dies: (1) new die materials, (2) better coatings
Coatings	Steel (VT)	Improve die and roll materials and coatings and lubricants used in die and roll systems
Composites	PM^2 (SI)	Co-sintering composites with different materials
Composites	PM^2 (SI)	Custom composite powders of different materials (biological, plastics, etc.)
Corrosion-, erosion-, wear-resistant materials	Advanced Ceramics (SI)	Improve resistance to the use environment (e.g., oxidation, corrosion)
Corrosion-, erosion-, wear-resistant materials	Chemicals (VT)	Develop new materials
Corrosion-, erosion-, wear-resistant materials	Forest Products (VT)	Develop new material for the industry's processing equipment which are cheaper to use, less expensive to maintain, and stand up to the nature of chemical processes
Corrosion-, erosion-, wear-resistant materials	Heat Treating (SI)	Improved alloys that extend the life and operating temperature range of furnace hardware and fixtures
Corrosion-, erosion-, wear-resistant materials	Mining (VT)	Develop new materials to improve wear resistance
High-temperature materials and refractories	Aluminum (VT)	Develop more durable refractory materials (NMAB)
High-temperature materials and refractories	Chemicals (VT)	Develop longer life refractories that are field repairable and ductile
High-temperature materials and refractories	Glass (VT)	Develop longer lasting materials in addition to refractories
High-temperature materials and refractories	Glass (VT)	Develop new refractories
High-temperature materials and refractories	Glass (VT)	Develop refractories that do not introduce defects

RAND

P--Advanced material manufacture using novel nanophase materials (Part II of II)
(This project links 10 MIRN Categories, 4 SI and 8 IOF industries)

MIRN Category	Roadmap	Need
High-temperature materials and refractories	Heat Treating (SI)	Improved alloys that extend the life and operating temperature range of furnace hardware and fixtures
High-temperature materials and refractories	PM^2 (SI)	Low-creep, high-temperature materials
High-temperature materials and refractories	Steel (VT)	Develop improved refractories for walls, or better ways to seal existing leaking through walls
Low-friction/lubricants	Steel (VT)	Improve die and roll materials and coatings and lubricants used in die and roll systems
Process design and improvement	Forging (SI)	New materials to reduce needs for processing: (1) colder working temperature, (2) no heat treating, (3) no conditioning
Process design and improvement	Heat Treating (SI)	Alloys that enable some heat treating operations to be eliminated (to shorten cycle and/or save energy)
Process design and improvement	Petroleum (VT)	Catalysts:(1) Develop >5 new chemical catalysts for low-temp environments, (2) increase catalyst life by 2-fold through new sulfur and nitrogen-tolerant catalysts, (3) single, non-energy requiring biocatalyst for hydrocarbon and heteroatom conversion
Process design and improvement	Petroleum (VT)	Develop improved catalysts for deep diesel desulfurization
Raw materials	PM^2 (SI)	Economic manufacture of sub-micron particles at production scale
Raw materials	PM^2 (SI)	Fine particle technology and nanocrystalline powders: 1) compaction, 2) material properties, 3) sintering
Raw materials	PM^2 (SI)	Self-sintering powders
Tools and dies	Aluminum (VT)	Develop better tool and die materials with improved heat extraction capabilities (NMAB)
Tools and dies	Forging (SI)	Develop improved die materials
Tools and dies	Metal Casting (NMAB)	Develop Improved Dies: (1) new die materials, (2) better coatings
Tools and dies	Steel (VT)	Improve die and roll materials and coatings and lubricants used in die and roll systems

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The two tables on the previous page show the R&D needs addressed by the proposed PM^2 priority roadmap project "Advanced material manufacture using novel nanophase materials." Together, they list all of the R&D needs addressed by this project.

This project links ten MIRN Categories encompassing four SI and eight IOF industries.

Note: In these tables and in the following tables in this section, the needs are listed according to the MIRN Categories in which they fall, with the MIRN Categories listed in alphabetical order. The industry roadmaps, from which the R&D needs are derived, are also shown in alphabetical order under each MIRN Category.

P--Development of predictive tools for compression of time to describe properties (performance) at the component level (Math-based component design, processing and validation)
(This project links 5 MIRN Categories, 2 SI and 3 IOF industries)

MIRN Category	Roadmap	Need
Advanced forming	PM^2 (SI)	Understanding of basic process phenomena
Databases and properties	Aluminum (VT)	Develop integrated numerical methods for analysis and robust design of product process, and material
Design tools	Aluminum (VT)	Develop integrated numerical methods for analysis and robust design of product process, and material
Design tools	Metal Casting (VT)	Develop computer design tools to move from design concept to a design for manufacturing
Modeling and simulation	Aluminum (VT)	Develop integrated numerical methods for analysis and robust design of product process, and material
Modeling and simulation	Aluminum (VT)	Understand relationship of aluminum alloy composition & processing & its effect on microstructure and properties (zero earring, high strength formability can sheet product, develop 3000 series alloys for end stock beverage)
Modeling and simulation	Chemicals (VT)	Develop means to predict materials performance without empirical tests
Modeling and simulation	Heat Treating (SI)	Enhanced computer modeling of processes, which includes composition, distortion, resultant microstructure, and final properties
Modeling and simulation	Heat Treating (SI)	Integrated process model - mechanical
Modeling and simulation	PM^2 (SI)	Modeling of complete forming and strengthening processes for a component
Modeling and simulation	PM^2 (SI)	Process modeling for pressing, sintering, gas flow in furnaces, and other processes
Modeling and simulation	PM^2 (SI)	Widely available user-friendly, math-based process models with realistic constraints
Process design and improvement	Aluminum (VT)	Develop integrated numerical methods for analysis and robust design of product process, and material

RAND

The table above shows the R&D needs addressed by the proposed PM^2 priority roadmap project "Development of predictive tools for compression of time to describe properties (performance) at the component level (math-based component design, processing and validation)."

This project links five MIRN Categories encompassing two SI and three IOF industries.

P--Development of sensor-based feedback control techniques to reduce process variation
(This project links 4 MIRN Categories, 4 SI and 3 IOF industries)

MIRN Category	Roadmap	Need
NDE and inspection	Advanced Ceramics (SI)	Develop intelligent processing (automated or semi-automated with sensors, NDE, etc.)
Process design and improvement	Advanced Ceramics (SI)	Develop intelligent processing (automated or semi-automated with sensors, NDE, etc.)
Process monitoring and control	Advanced Ceramics (SI)	Develop intelligent processing (automated or semi-automated with sensors, NDE, etc.)
Process monitoring and control	Forging (SI)	Develop closed-loop process controls for hot forging (requires sensors)
Process monitoring and control	Forging (SI)	Develop PC-based machine controllers
Process monitoring and control	Glass (VT)	Improve intelligent control of production and fabrication process
Process monitoring and control	Heat Treating (SI)	Improved process sensors, including those for carbon content, residual stress, and cleanliness. Also, more advanced controls that can fully exploit these and other sensors.
Sensors and sensor materials	Forest Products (VT)	Develop sophisticated real-time measurement and control systems for: (1) enviro-related, (2) process-related, (3) product quality, (4) large system controls, (5) expert systems
Sensors and sensor materials	Heat Treating (SI)	Improved process sensors, including those for carbon content, residual stress, and cleanliness. Also, more advanced controls that can fully exploit these and other sensors.
Sensors and sensor materials	Metal Casting (VT)	Develop smart controls and sensors for automation supervision
Sensors and sensor materials	PM^2 (SI)	Advanced controls for more accurate green compacting and sintering
Sensors and sensor materials	PM^2 (SI)	Non-intrusive, stable sensor materials for process control
Sensors and sensor materials	PM^2 (SI)	Novel use of new or existing sensor technology to monitor particle size, particle size distribution, flow rates, and furnace conditions
Sensors and sensor materials	PM^2 (SI)	System-based, closed-loop feedback controls (sintering problem feeds back to earlier process)

RAND

The table above shows the R&D needs addressed by the proposed PM^2 priority roadmap project "Development of sensor-based feedback control techniques to reduce process variation."

This project links four MIRN Categories encompassing four SI and three IOF industries.

P--Electromagnetic circuit design with three-dimensional P/M magnets and core components (This project links 3 MIRN Categories, 3 SI and 1 IOF industries)

MIRN Category	Roadmap	Need
High-temperature materials and refractories	Forging (SI)	Develop induction heating system with higher efficiency (e.g. reshapable coils) or improved materials or insulation
Magnetic materials	PM^2 (SI)	Innovative magnetic materials
Process design and improvement	Forging (SI)	Develop induction heating system with higher efficiency (e.g. reshapable coils) or improved materials or insulation
Process design and improvement	Heat Treating (SI)	Induction coils that make optimum use of the electromagnetic field distribution for heating
Process design and improvement	Steel (VT)	Energy Use: Develop superconducting electrodes, higher power induction melting, economic microwave applications

RAND

The table above shows the R&D needs addressed by the proposed PM^2 priority roadmap project "Electromagnetic circuit design with three-dimensional P/M magnets and core components."

This project links three MIRN Categories encompassing three SI industries and one IOF industry.

P--Joining of P/M components for greater functionality (Part I of II) (This project links 5 MIRN Categories, 3 SI and 5 IOF industries)

MIRN Category	Roadmap	Need
Corrosion-, erosion-, wear-resistant materials	Welding & Joining (SI)	Development of more weldable corrosion-resistant materials (Very high priority)
High-temperature materials and refractories	Welding & Joining (SI)	Weldable materials sustainable of higher temperatures
Joining and welding	Advanced Ceramics (SI)	Develop field joining techniques (offsite)
Joining and welding	Advanced Ceramics (SI)	Develop joining techniques to reduce stresses (ceramic/metal, ceramic/plastic, ceramic/ceramic)
Joining and welding	Aluminum (VT)	Eliminate pre-treatment for joining (bonding, spot welding) /Non-mechanical joining methods for non-weldable alloys
Joining and welding	Chemicals (VT)	Explore joining methods for ODS alloys
Joining and welding	Chemicals (VT)	Investigate joining/fabrication techniques for ceramics and other brittle materials for chemical processing
Joining and welding	Forest Products (VT)	Improved welding techniques for system fabrication and construction
Joining and welding	Metal Casting (VT)	Demonstrate effective joining techniques for new and dissimilar cast materials - to join new alloys (especially for automotive applications)
Joining and welding	PM^2 (SI)	Improved welding and joining techniques
Joining and welding	Steel (VT)	Develop and optimize alternative joining methods
Joining and welding	Welding & Joining (SI)	Development of more weldable corrosion-resistant materials (Very high priority)
Joining and welding	Welding & Joining (SI)	Improvements in dissimilar materials joining (High priority)
Joining and welding	Welding & Joining (SI)	Inclusion of weldability and manufacturability in new material development (Top priority)
Joining and welding	Welding & Joining (SI)	Joining processes for dissimilar materials (Very high priority)

RAND

P--Joining of P/M components for greater functionality (Part II of II) (This project links 5 MIRN Categories, 3 SI and 5 IOF industries)

MIRN Category	Roadmap	Need
Joining and welding	Welding & Joining (SI)	Materials and/or process developments to enable aluminum alloys to be welded with minimal material property degradation
Joining and welding	Welding & Joining (SI)	More alloy development in general
Joining and welding	Welding & Joining (SI)	Weldable alloys that reduce need for pre and post heat treatment (Very high priority)
Joining and welding	Welding & Joining (SI)	Weldable materials sustainable of higher temperatures
Joining and welding	Welding & Joining (SI)	Weldable, cost-effective materials that met performance requirements of future automotive structures --- good strength-to-weight ratios, corrosion resistance, and/or high-temperature strength (Top priority)
Joining and welding	Welding & Joining (SI)	Welding of lighter-weight materials used in low-emission vehicles (Top priority)
Process design and improvement	Welding & Joining (SI)	Improvements in dissimilar materials joining (High priority)
Process design and improvement	Welding & Joining (SI)	Joining processes for dissimilar materials (Very high priority)
Process design and improvement	Welding & Joining (SI)	Materials and/or process developments to enable aluminum alloys to be welded with minimal material property degradation
Process design and improvement	Welding & Joining (SI)	Weldable alloys that reduce need for pre and post heat treatment (Very high priority)
Raw materials	Welding & Joining (SI)	More alloy development in general

RAND

The two tables on the previous page show the R&D needs addressed by the proposed PM^2 priority roadmap project "Joining of P/M components for greater functionality." Together, the tables list all of the R&D needs addressed by this project.

This project links five MIRN Categories encompassing three SI and five IOF industries.

P--Manufacture of full-density, high-tolerance components using single press and sintering techniques (Part I of II) (This project links 9 MIRN Categories, 4 SI and 5 IOF industries)

MIRN Category	Roadmap	Need
Advanced forming	Advanced Ceramics (SI)	Improve fabrication processes and reduce equipment costs
Advanced forming	Aluminum (VT)	Advanced forming and net-shape/near net-shape technology (semi-solid casting, casting spay forming, spray forming, physical vapor deposition, PM technology, rapid solidification)
Advanced forming	PM^2 (SI)	Form and sinter in one process
Advanced forming	PM^2 (SI)	Non-traditional processing techniques
Casting	Aluminum (VT)	Develop better tool and die materials with improved heat extraction capabilities (NMAB)
Coatings	Metal Casting (NMAB)	Develop Improved Dies: (1) new die materials, (2) better coatings
Coatings	PM^2 (SI)	Wear-resistant die materials or coatings
Coatings	Steel (VT)	Improve die and roll materials and coatings and lubricants used in die and roll systems
Corrosion-, erosion-, wear-resistant materials	Chemicals (VT)	Develop new materials
Corrosion-, erosion-, wear-resistant materials	Chemicals (VT)	Develop new materials
Corrosion-, erosion-, wear-resistant materials	Heat Treating (SI)	Improved alloys that extend the life and operating temperature range of furnace hardware and fixtures
Corrosion-, erosion-, wear-resistant materials	PM^2 (SI)	Wear-resistant die materials or coatings
High-temperature materials and refractories	Glass (VT)	Develop longer lasting materials in addition to refractories
High-temperature materials and refractories	Heat Treating (SI)	Improved alloys that extend the life and operating temperature range of furnace hardware and fixtures
High-temperature materials and refractories	Steel (VT)	Maintain the good properties achieved by newer refractories, while minimizing cost and consumption and ensuring safety
Low-friction/lubricants	Steel (VT)	Improve die and roll materials and coatings and lubricants used in die and roll systems

RAND

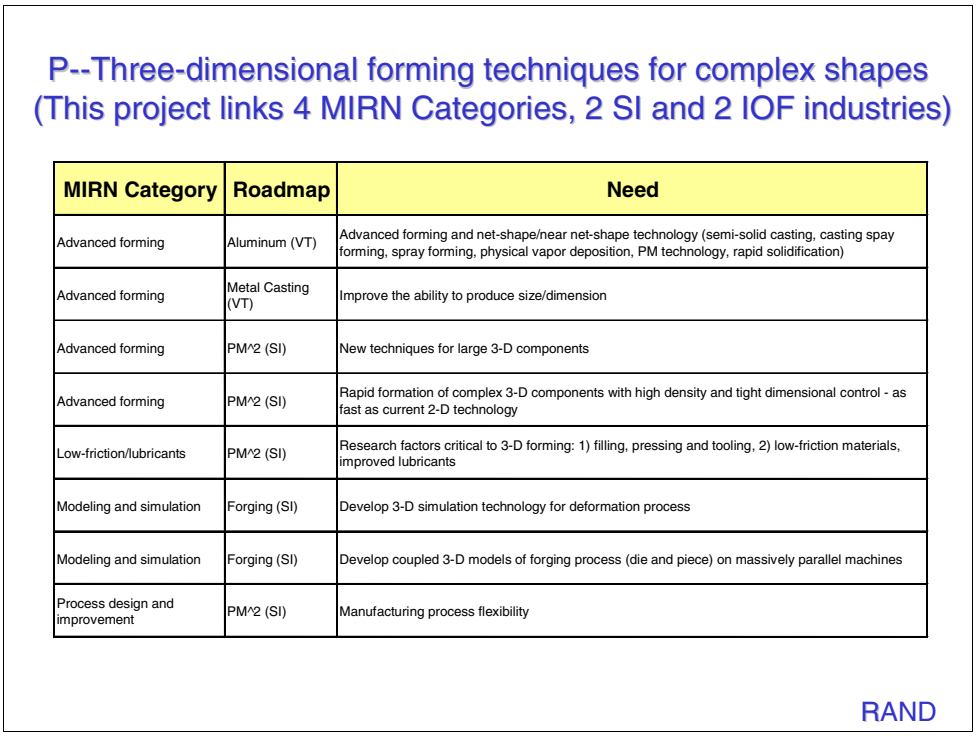
P--Manufacture of full-density, high-tolerance components using single press and sintering techniques (Part II of II) (This project links 9 MIRN Categories, 4 SI and 5 IOF industries)

MIRN Category	Roadmap	Need
Process design and improvement	Advanced Ceramics (SI)	Establish reliable fabrication capability for large-volume components
Process design and improvement	Advanced Ceramics (SI)	Improve sintering processes to near-100% uniformity (Top priority)
Process design and improvement	Heat Treating (SI)	Lower cost heat treatable alloys
Process design and improvement	PM^2 (SI)	Manufacturing process flexibility
Standards, product quality, testing	PM^2 (SI)	Materials single-pressed to full density
Tools and dies	Aluminum (VT)	Develop better tool and die materials with improved heat extraction capabilities (NMAB)
Tools and dies	Forging (SI)	Develop improved die materials
Tools and dies	Forging (SI)	Develop next-generation die manufacturing technology
Tools and dies	Metal Casting (NMAB)	Develop Improved Dies: (1) new die materials, (2) better coatings
Tools and dies	PM^2 (SI)	Wear-resistant die materials or coatings
Tools and dies	Steel (VT)	Improve die and roll materials and coatings and lubricants used in die and roll systems

RAND

The two tables on the previous page show the R&D needs addressed by the proposed PM^2 priority roadmap project "Manufacture of full-density, high-tolerance components using single press and sintering techniques." Together, the tables list all of the R&D needs addressed by this project.

This project links nine MIRN Categories encompassing four SI and five IOF industries.



P--Three-dimensional forming techniques for complex shapes
(This project links 4 MIRN Categories, 2 SI and 2 IOF industries)

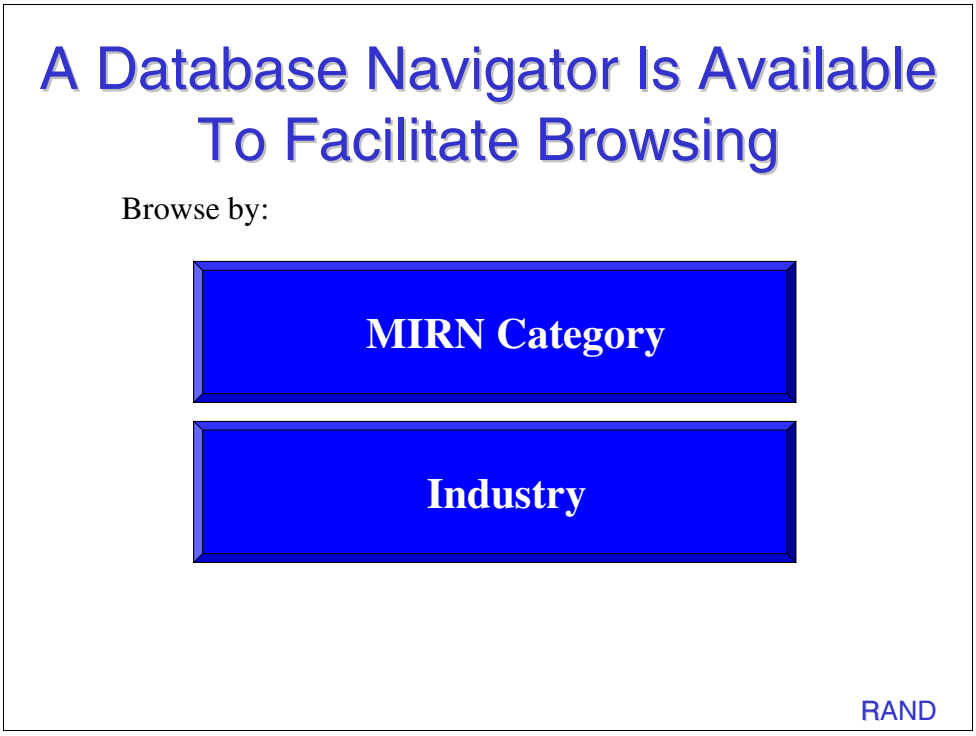
MIRN Category	Roadmap	Need
Advanced forming	Aluminum (VT)	Advanced forming and net-shape/near net-shape technology (semi-solid casting, casting spay forming, spray forming, physical vapor deposition, PM technology, rapid solidification)
Advanced forming	Metal Casting (VT)	Improve the ability to produce size/dimension
Advanced forming	PM^2 (SI)	New techniques for large 3-D components
Advanced forming	PM^2 (SI)	Rapid formation of complex 3-D components with high density and tight dimensional control - as fast as current 2-D technology
Low-friction/lubricants	PM^2 (SI)	Research factors critical to 3-D forming: 1) filling, pressing and tooling, 2) low-friction materials, improved lubricants
Modeling and simulation	Forging (SI)	Develop 3-D simulation technology for deformation process
Modeling and simulation	Forging (SI)	Develop coupled 3-D models of forging process (die and piece) on massively parallel machines
Process design and improvement	PM^2 (SI)	Manufacturing process flexibility

RAND

The table above shows the R&D needs addressed by the proposed PM^2 priority roadmap project "Three-dimensional forming techniques for complex shapes."

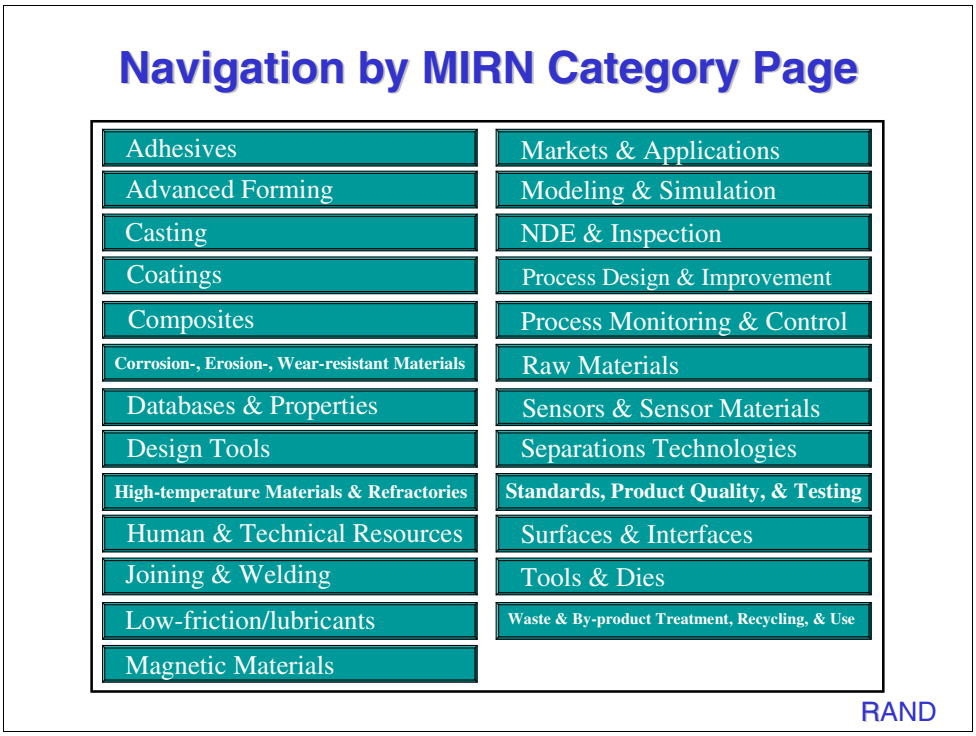
This project links four MIRN Categories encompassing two SI and two IOF industries.

DATABASE NAVIGATOR

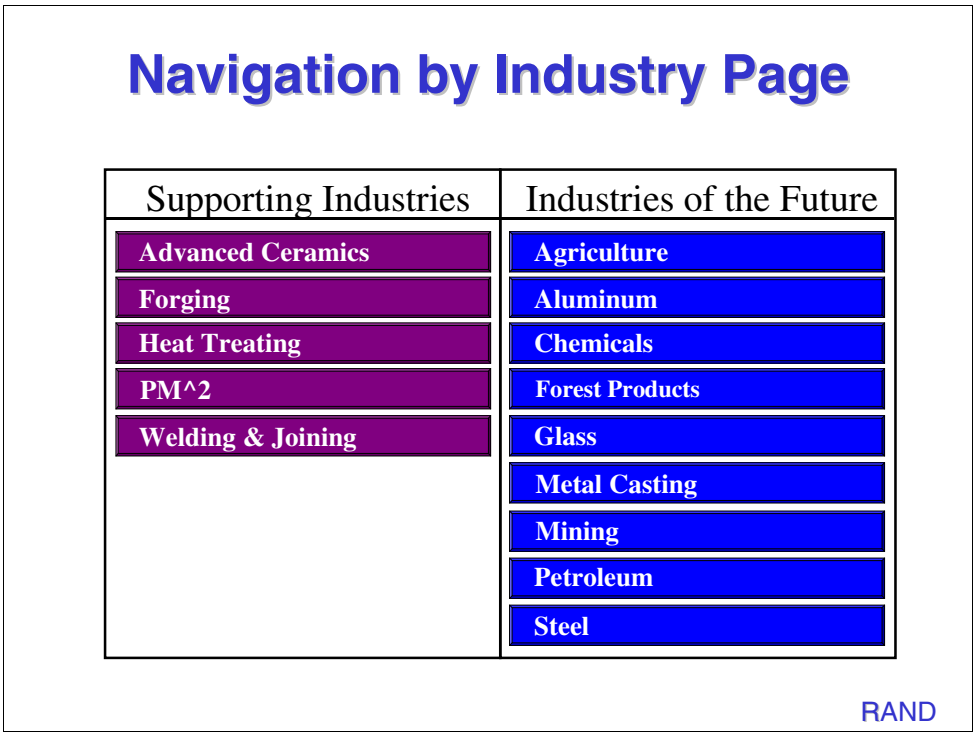


This section describes a Microsoft PowerPoint–based navigational tool that we developed to facilitate browsing the database that is in Microsoft Access format. We refer to the tool as the "Database Navigator" or simply the "navigator." The illustrations in this section replicate the slides as they would appear within the navigational tool. Both the Access database and the navigational tool, which is in HTML, are on the CD accompanying this briefing; however, one cannot navigate through the electronic version of this briefing on the CD by clicking the text or figures. The purpose of the following discussion is to show how we used the navigator for this study, and how others can use it to identify and analyze MIRN Category links.

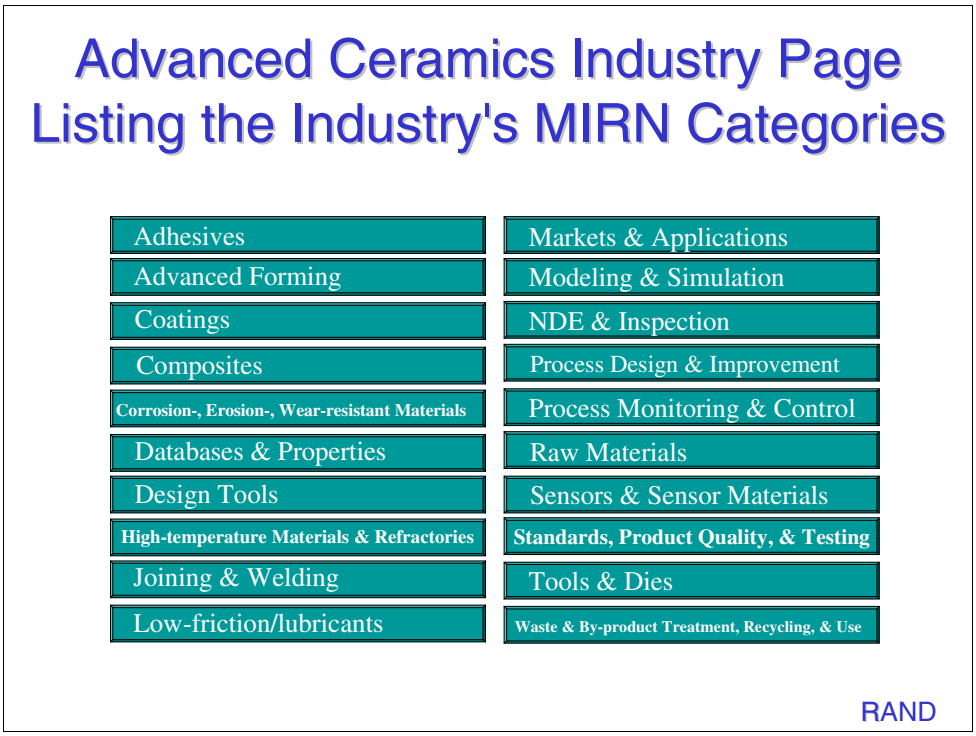
The figure above is the first slide in the navigator. The user begins by clicking on either of the boxes to choose browsing by MIRN Category or browsing by industry. The following figures show examples of the navigator slides. We also discuss how the tool can be used to identify and analyze MIRN Category links. The navigator includes all information in the database on R&D needs, projects, and MIRN Categories.



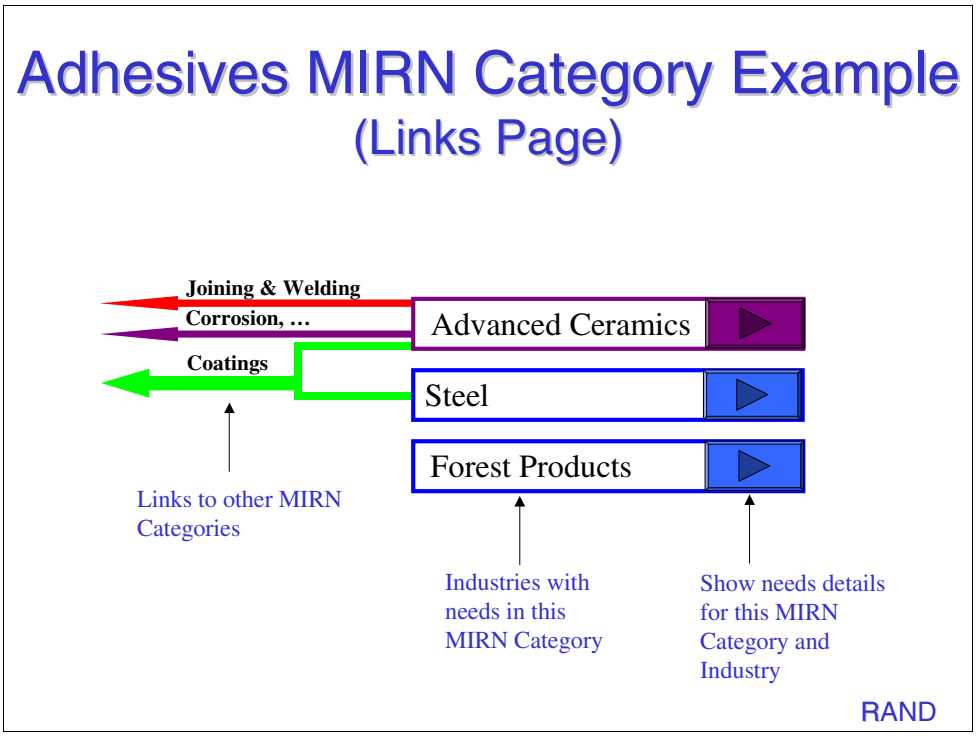
The figure above appears after the user clicks on the "MIRN Category" box in the first slide of the navigator. It lists the 25 MIRN Categories. Clicking on any of these categories takes the user to the first slide in a set of slides that includes all of the information on R&D needs, projects, and MIRN Category links for that MIRN Category.



The figure above appears when the user clicks on the "Industry" box in the first slide of the navigator. It lists the five Supporting Industries and nine Industries of the Future. Clicking on any of these industries takes the user to a slide that lists all of the MIRN Categories that include R&D needs from that industry's roadmap. Clicking on any of those MIRN Categories then takes the user to a set of slides that includes all of the information on R&D needs, projects, and MIRN Category links for that MIRN Category.



The figure above appears when the user clicks on the "Advanced Ceramics" box in the previous slide. This page lists the 20 MIRN Categories that include R&D needs from the Advanced Ceramics roadmap. Clicking on any of these categories takes the user to the first slide in a set of slides that includes all of the information on R&D needs, projects, and MIRN Category links for that MIRN Category. The navigator includes a slide such as this one for each of the five Supporting Industries and nine Industries of the Future.

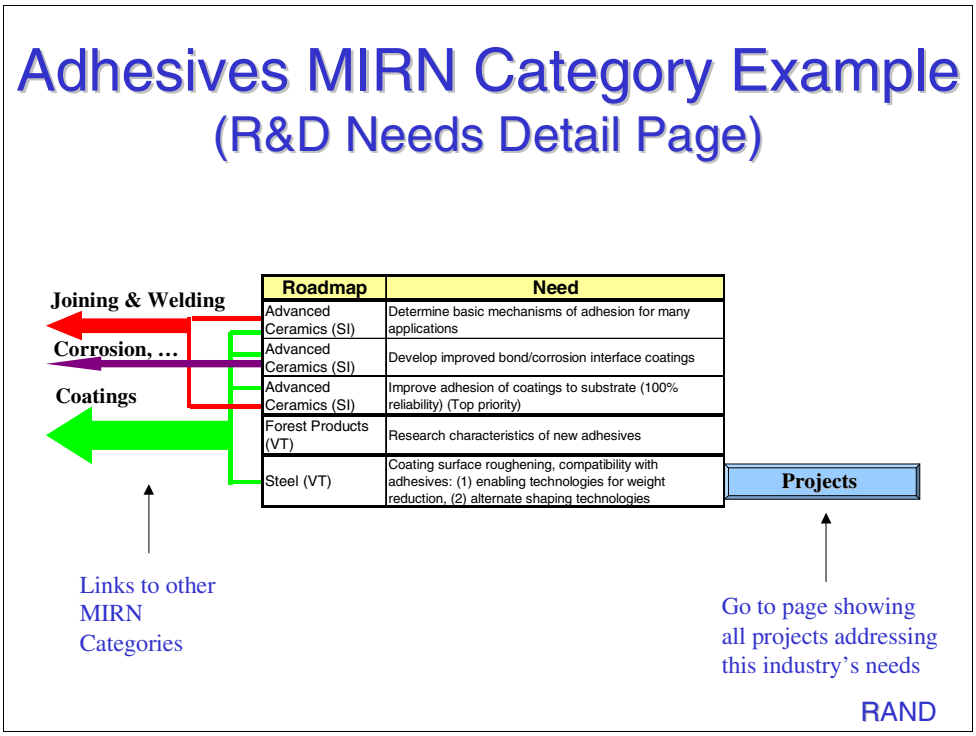


The illustration above appears when the user views a MIRN Category (in this case "Adhesives") from either an Industry page or the MIRN Categories page.

The boxes on the right side of the page list the industries that have R&D needs within this MIRN Category. Clicking on any of these boxes takes the user to a page that shows the R&D needs for that industry that fall within this MIRN Category.

The arrows on the left side show the MIRN Category links information for this MIRN Category. The width of the arrows indicates the number of industries encompassed by the MIRN Category links. In this example for "Adhesives," there are MIRN Category links to Joining and Welding and to Corrosion-, Erosion-, and Wear-Resistant Materials via needs from the Advanced Ceramics industry roadmap. There are also links to the Coatings MIRN Category via industry needs from the Advanced Ceramics and Steel roadmaps. The fact that no arrows emanate from the Forest Products box shows that although there are adhesives needs in the Forest Products roadmap, none of them fall into any other MIRN Category; therefore, there are no MIRN Category links for Adhesives via Forest Products.

Clicking on any arrow, such as any of those in the above illustration, sends the user to the MIRN Category slide for that arrow. A slide such as this one exists in the navigator for each of the 25 MIRN Categories.



This illustration above appears when the user clicks on any of the industry boxes in the previous slide. The above slide shows all the industries and their R&D needs for this MIRN Category, from which is drawn the detailed MIRN Category links information (i.e., which R&D needs in which industry roadmaps fall into multiple MIRN Categories to create the MIRN Category links). For example, it shows that all three R&D needs for the Advanced Ceramics industry and the single R&D need for the Steel industry involve both adhesives (or adhesion) *and* coatings, while only two of the needs (for Advanced Ceramics) deal with adhesives (or adhesion) *and* joining and welding, and only one need (also for Advanced Ceramics) deals with adhesives (or adhesion) *and* corrosion. It also shows that the R&D need for Forest Products deals *only* with adhesives.

Note: The arrows on the left side of the slide were added for this MIRN Category example solely to illustrate these relationships. Other than for the Adhesives MIRN Category, the navigator does not display such arrows (that is, when the user goes one level down to the R&D needs details, the arrows no longer appear, except in the Adhesives MIRN Category). One can, however, return to any MIRN Category "home page" to see the arrows to all other linked MIRN Categories.

Clicking on the box labeled "Projects" in the above illustration produces a slide that lists all of the projects addressing the needs of the roadmap for the industry adjacent to the box (in this case, Steel). Projects boxes appear only for those industries that have needs in this MIRN Category that are addressed by research projects.

Adhesives MIRN Category Example
(Research Projects Addressing Steel Industry Needs in the MIRN Category)

Roadmap	Project	Funding Source	Need	Performance Target
Steel (VT)	Generic approach to improved semi-solid forming of metals	OS	Coating surface roughening, compatibility with adhesives: (1) enabling technologies for weight reduction, (2) alternate shaping technologies	Improve Product Development
Steel (VT)	Semi-solid metal freeform fabrication	OS	Coating surface roughening, compatibility with adhesives: (1) enabling technologies for weight reduction, (2) alternate shaping technologies	Improve Product Development
Steel (VT)	Surface quality of automotive sheet steels	VT	Coating surface roughening, compatibility with adhesives: (1) enabling technologies for weight reduction, (2) alternate shaping technologies	Improve Product Development
Steel (VT)	Uniform droplet processing	IMF	Coating surface roughening, compatibility with adhesives: (1) enabling technologies for weight reduction, (2) alternate shaping technologies	Improve Product Development

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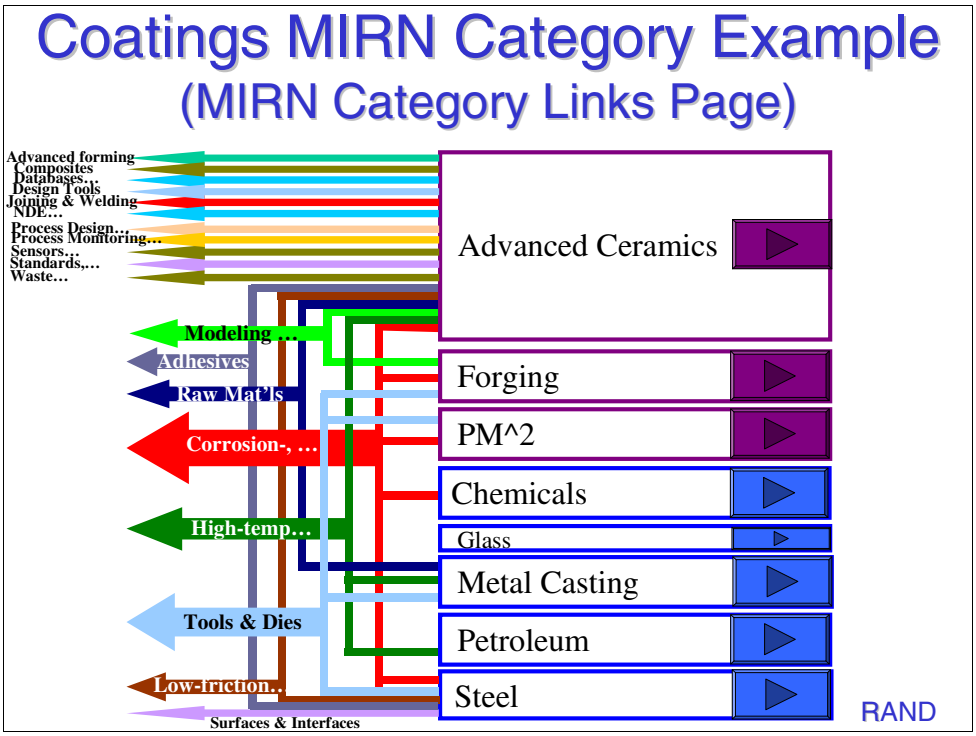
The figure above appears when the user clicks on the "Projects" box in the previous figure. This slide shows all of the research projects that address R&D needs (and performance targets, where appropriate) in the roadmap for the industry adjacent to the Projects box. The slide also shows the DOE funding sources for these projects (which could be the IOF Vision Team, the Supporting Industry program, the Industrial Materials for the Future program, the OIT Financial Assistance Program [now part of the DOE Weatherization and Intergovernmental Grants program], or the DOE Office of Science).



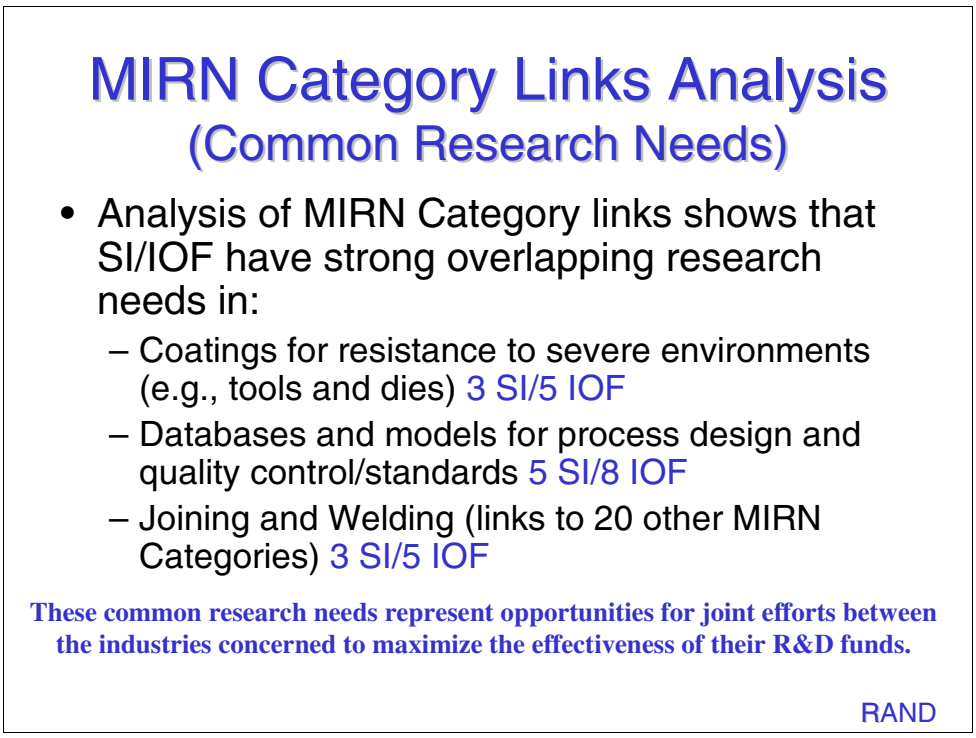
The previous set of figures illustrates how one may use the navigator to explore the information in the database by MIRN Category or by industry, using Adhesives (a MIRN Category with a relatively small number of needs, industries, and links) as an example. The slide above illustrates a much richer category in terms of numbers of links. The Coatings category has 19 MIRN Category links via three Supporting Industries (Advanced Ceramics, Forging, PM^2) and four Industries of the Future (Chemicals, Metal Casting, Petroleum, Steel). Note that Glass has R&D needs that fall within the Coatings MIRN Category, but none of those needs also fall within any other MIRN Category; therefore, there are no MIRN Category links for Coatings via the needs of the Glass industry.

Using the navigator, one can move between Coatings and the other MIRN Categories to which it is linked by clicking on the arrows on the left side of the slide. One can also review the industries, R&D needs, and research projects that create these links by clicking on the appropriate boxes.

The navigator can be a powerful tool for identifying groups of industries with common research needs, and especially the common research needs of groups of industries that cross the boundaries of multiple research areas. It also allows a quick analysis of which MIRN Category links are being addressed by certain projects and which are not and the funding sources for the projects. The funding source data provide information on the likely characteristics of a research project based on the missions of the various DOE

programs (e.g., basic or applied, near-term or long-term). The funding source also provides information for further analysis of project status and project results, if desired.

MIRN CATEGORY LINKS ANALYSIS

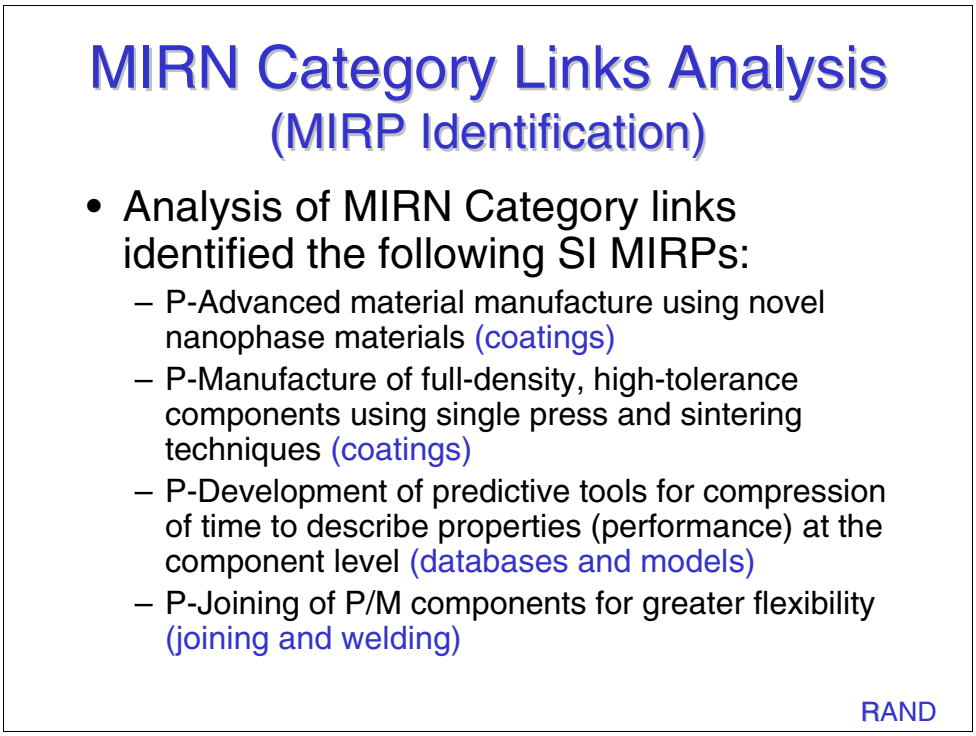


RAND used the navigator to analyze MIRN Category links across the 25 MIRN Categories, the five Supporting Industries examined for this study, and the nine Industries of the Future. Browsing by MIRN Category showed consistent MIRN Category links between the Coatings; Corrosion-, Erosion-, and Wear-Resistant Materials; High-Temperature Materials and Refractories; and Tools and Dies categories through the Advanced Ceramics, Forging, PM^2, Chemistry, Glass, Metal Casting, Petroleum, and Steel industries. These three SI and five IOF industries thus have strong overlapping research needs in coatings for resistance to severe environments.

Browsing by MIRN Category also identified MIRN Category links between Databases and Properties and Modeling and Simulation involving all five SIs and all nine IOFs except Agriculture. These two MIRN Categories were further linked to Design Tools, Process Design and Improvement, and Standards, Product Quality, and Testing, as well as to the Coatings MIRN Category mentioned in the previous paragraph.

Finally, the navigator showed that Joining and Welding (which is both a MIRN Category and a Supporting Industry) is linked to 20 of the 24 other MIRN Categories through Advanced Ceramics, PM^2, Aluminum, Chemicals, Forest Products, Metal Casting, and Steel.

These common research needs represent opportunities for joint efforts between the industries concerned to maximize the impact of their R&D funds.



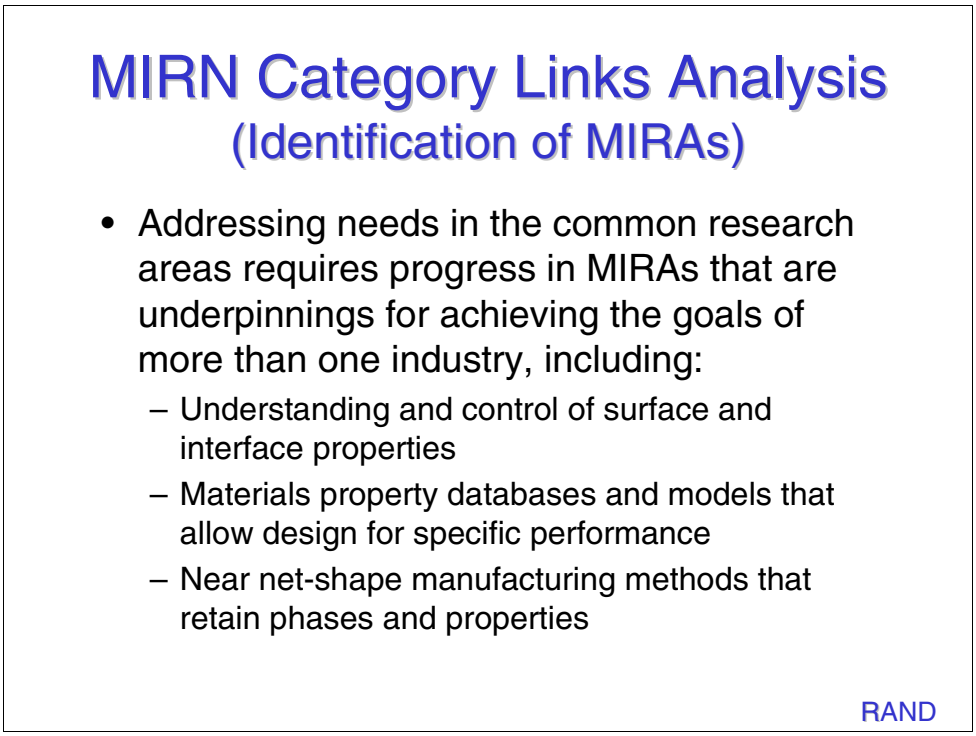
As noted previously, Supporting Industry research projects typically address multiple R&D needs. Often, these needs are from multiple industry roadmaps, which indicate that the project is a MIRP. Using the navigator to browse the research projects under each of the common research needs mentioned on the previous page, we identified the following proposed priority SI projects as MIRPs (the letter P indicates the projects were proposed by an industry roadmap team):

P–Advanced material manufacture using novel nanophase materials addresses research needs in coatings for resistance to severe environments from all SI roadmaps, except the roadmap for the Joining and Welding industry, and all IOF roadmaps, except the roadmap for Agriculture.

P–Manufacture of full-density, high-tolerance components using single press and sintering techniques addresses research needs in coatings for resistance to severe environments from the Aluminum, Chemistry, Forging, Glass, Heat Treating, Metal Casting, and Steel industry roadmaps.

P–Development of predictive tools for compression of time to describe properties (performance) at the component level addresses research needs in databases and models for process design and quality control/standards from the Aluminum, Chemistry, Heat Treating, Metal Casting, and PM^2 industry roadmaps.

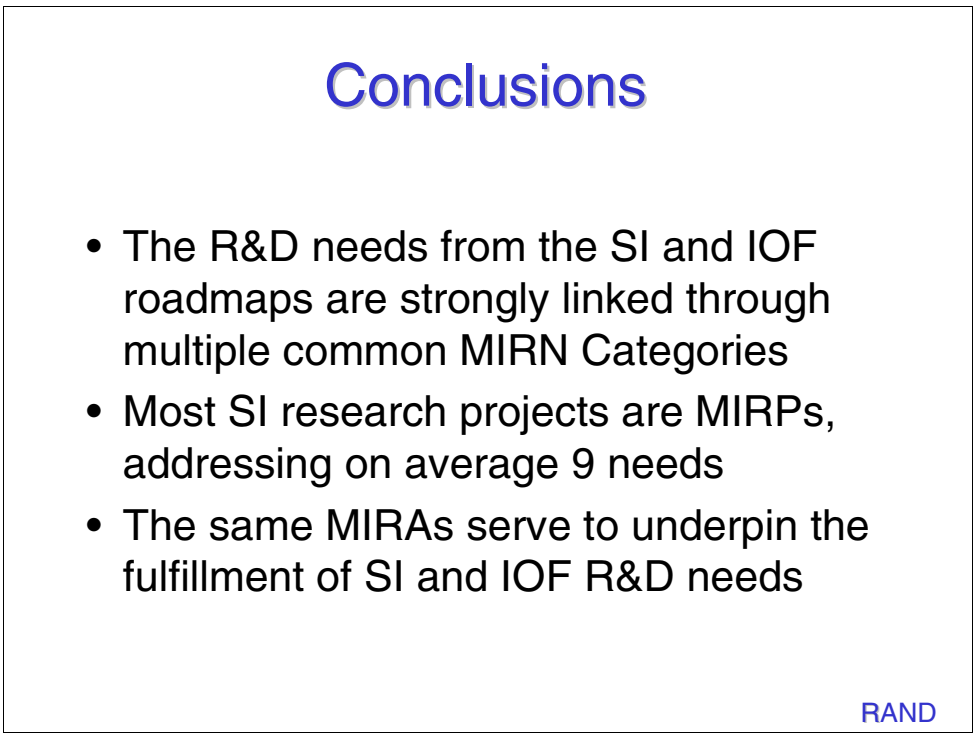
P–Joining of P/M components for greater flexibility addresses research needs in joining and welding from the Advanced Ceramics, Aluminum, Chemistry, Forest Products, Metal Casting, PM^2, Steel, and Joining and Welding industry roadmaps.



The MIRN Category links analysis also points the way toward important multiple-industry research areas in which the needs of more than one industry cross the boundaries of more than one research area. These MIRAs are the underpinnings of those common research areas. For example, the development and application of improved coatings for severe environments depend upon progress in the understanding and control of surface and interface properties of materials with the ability to withstand those environments (e.g., ceramics for new refractories or metal alloys tailored for high-temperature oxidation or corrosion resistance). The design of materials for industrial process environments requires materials property databases and models that represent those environments with sufficient precision and reproducibility. Progress in solving joining and welding problems identified in both SI and IOF roadmaps depends on both of these MIRAs, i.e., it requires understanding and control of surfaces and interfaces and accurate and comprehensive materials property databases and models.

As noted previously, MIRAs can also be identified via MIRPs that link MIRN Categories. In the example above, manufacture of full-density, high-tolerance components using single press and sintering techniques is part of a group of MIRPs linking Advanced Forming, Coatings, and Tools and Dies MIRNs through the Aluminum, Forging, Heat Treating, Metal Casting, PM^2, and Steel industries. These MIRPs point toward near net-shape manufacturing methods that retain phases and properties.

CONCLUSIONS AND RECOMMENDATIONS



We draw the following conclusions from our analysis of the SI and IOF industry roadmaps and the DOE projects that address the R&D needs and performance targets described in those roadmaps:

- The R&D needs in the SI and IOF roadmaps are strongly linked through multiple common MIRN Categories. As shown earlier in the "Database Characteristics and Analysis" section of this briefing, 14 of the 25 MIRN Categories encompass research needs from more than half of the five SI and nine IOF industries.
- Most SI research projects address research needs in multiple industries, and are thus MIRPs. As also shown in the "Database Characteristics and Analysis" section, the SI projects, on average, address almost nine R&D needs, and more than 40 percent of those needs are in the IOF industry roadmaps.
- The same MIRAs serve to underpin the fulfillment of both SI and IOF R&D needs. This conclusion is illustrated by the common research needs (noted at the beginning of the previous section, "MIRN Category Links Analysis") that address multiple SI and IOF industries and by the MIRAs (listed at the end of the previous section) that are the underpinnings of the common research areas. The "Powder Metallurgy and

Particulate Materials Example" section, which illustrates how seven proposed priority PM^2 projects link 12 industries through 19 different MIRN Categories, further reinforces this conclusion.

Based on our analysis, we offer the following recommendations:

- The DOE/Industrial Technologies programs should sponsor and participate in workshops that include multiple-industry teams and that cross the boundaries of multiple research areas. These crosscutting workshops would differ in both participation and content from the roadmap workshops that these programs typically sponsor. Participants should include members of all industry teams with relevant R&D needs and guest speakers who have knowledge of ongoing and prospective research projects that could address those needs. The format should allow for presentations on R&D needs, detailed technical presentations at the project level, and discussions among researchers and end users of the research, all of which would ultimately lead to identification of priority research projects. The first of these workshops could address common research areas identified in this briefing: i.e., coatings for resistance to severe environments; databases and models for process design and quality control/standards; and joining and welding. The participating industries should at least include those that have roadmapped needs within the linked MIRN Categories relating to these research areas, but invitations could also be extended to other industries.
- The DOE/IT programs should coordinate their request for proposal solicitations to allow for joint research projects, where appropriate, that would address their common R&D needs. The workshops discussed in the previous paragraph could identify such opportunities. The MIRAs that serve to underpin the common research

areas, and in which the needs of more than one industry cross the boundaries of more than one research area, are another source of joint RFP solicitations and joint research project opportunities. Three such MIRAs are discussed at the end of the previous section.

- The DOE/IT staff should use the database RAND developed for this study to facilitate further discussion of links between DOE/IT programs. This dialogue could be initiated through discussions of MIRN and MIRN Category links, and the relevant MIRPs, by the program staff responsible for the industries that have the roadmapped needs being addressed and/or that are conducting projects addressing those needs. These discussions should be aimed at identifying common research needs and identifying underlying research problems that, if solved, would allow industries to meet those needs. Joint projects could then be funded to address those problems, after which each team would then separately fund projects aimed at their industry-specific needs. Through regular updating of the roadmaps and database, this process will continue to provide the means to identify and address research needs that industries have in common and opportunities for joint projects within common research areas.

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