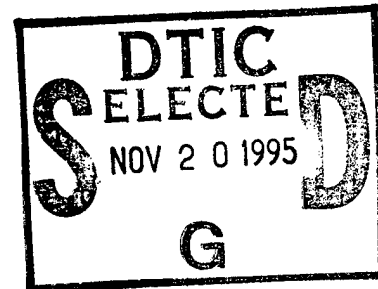


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ASSESSING THE ECONOMIC AND NATIONAL SECURITY BENEFITS
FROM PUBLICLY FUNDED TECHNOLOGY INVESTMENTS:
AN IDA ROUND TABLE

Editors:
Richard H. White
Jay Stowsky
Scott Hauger



September 1995

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INSTITUTE FOR DEFENSE ANALYSES

IDA Central Research Program

PREFACE

This volume was prepared from a verbatim transcript recorded at an IDA Round Table held on April 27, 1995, and organized according to major themes and topics. In some cases it was felt that the sense of the participants was best presented in their own vernacular, while in other cases concepts were clarified or pared by the editors. Every effort was made to retain the substantive content of the Round Table discussions, and to this end all participants were afforded an opportunity to review a final draft of the document prior to its publication.

Review comments of an editorial or stylistic nature were generally incorporated into the document's text. Comments regarding the substance of the text or which would have altered the record are handled as footnotes to the text and marked as "Review Note."

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INTRODUCTION

On April 27, 1995, the Institute for Defense Analyses (IDA) conducted a Round Table discussion entitled "Assessing the Economic and National Security Benefits of Publicly Funded Technology Investments." This meeting was held to explore two areas:

- (1) practical issues that government agencies should consider in selecting technology investments, and
- (2) criteria for assessing or measuring the success of selected investments.

The co-chairs of the Round Table were Joseph Stiglitz, chair of the President's Council of Economic Advisors (CEA); John Gibbons, director of the Office of Science and Technology Policy (OSTP); and Christopher Jehn, director of IDA's Strategy, Forces, and Resources Division.

This document summarizes and highlights the main discussions of the day. Dr. Gibbons first established the focus of the Round Table in his keynote address. This was followed by three sessions combining presentations and discussions by Round Table participants that dealt in detail with a set of current issues concerning the appropriate methods of establishing objectives and measuring the outcomes of national investment in new technologies. Those sessions were:

- (1) Decision Criteria for Technology Investments: Understanding the Rationales for Commercial and Dual-use Technology Programs
- (2) Tailoring Metrics to Economic Policy Objectives: The Case of ATP, MEP, and the NIST Laboratories
- (3) Metrics for Multiple Policy Objectives: The Case of TRP and Dual-use.

Economic studies have consistently shown that the private and social returns on investments in R&D are very high—indeed, much higher than returns on investments in other areas. Estimating expected returns on science and technology investments in advance, or *ex ante*, enables decision makers to make wise use of limited public resources. One role of metrics, therefore, is to assist decision makers by providing orderly information on the likely impact of proposed investments, based upon historical observation and experience.

Metrics are also an important part of designing good incentive structures. Today we focus increasingly on measured or anticipated performance in designing programs and selecting areas for investment. If one can measure performance, then one can relate rewards to performance. This is a key to developing efficient and just reward systems. At the same time, basing rewards on inappropriate or inaccurate measures of performance may lead to more harm than good.

Metrics also support retrospective, or *ex post* evaluations of investments and provide a basis for government decision makers to evaluate and discuss the benefits of investments in science and technology. Case studies are particularly effective in this regard. To be effective, however, such case studies must relate to the everyday experiences of the lay public, so that they can know how the fruits of technology investment affect their lives, from home entertainment to surgery. Such case studies are probably the most forceful way of educating Congress and the American people about the value of S&T investments.

Dr. Gibbons established in his keynote address that the government needs to agree on valid metrics to effectively assess technology investments by the public sector. Round Table participants discussed three functions of metrics as they relate to the economic assessment of the government's technology investments. This document is meant to serve as a summary record of those discussions.

BACKGROUND

A transition in federal science and technology (S&T) policy is occurring in the dynamic political and economic environment created by the end of the Cold War and the simultaneous intensification of global economic competition. Investments in applied technologies are an important part of the current administration's efforts to foster long-term economic growth and national security. Current administration policy emphasizes explicit links between federal government technology programs and the goals and priorities of U.S. industry. Government-industry partnerships are understood to be increasingly important in strengthening America's global industrial competitiveness.

During the preceding half-century, technology advanced, in part, through the stimulus of government supported basic science.¹ Examples of this process may be found in the technological fruits of space- and military-related research conducted by the

¹ Vannevar Bush wrote of "government-supported basic science" in, *Science, the Endless Frontier*.

National Aeronautics and Space Administration (NASA) and the Department of Defense (DoD).² Through the mid-1970s, commercial exploitation of the results of such federally funded R&D contributed to the United States' position as world leader in, science, national security, and economic competitiveness. The United States used its premier position to promote open trade and global economic development to the benefit of both its allies and itself. In the process, it also assisted in creating sophisticated economic competitors, the most successful of whom, many believe, use government policy more purposefully than has the U.S., to leverage science and technology for the advancement of their national welfare.

In the face of such foreign competition, policy makers in the United States today assign a higher priority to linking the technology activities of government and industry. At the same time, the end of the Cold War has profoundly altered the political landscape, changing the basis and the rationale by which government technology investments are made. The opportunities for commercial "spill-overs" to the commercial sector from defense-related research have diminished, so that today policies favoring dual-use and "spin-on" technologies appear to offer the greatest promise for simultaneously meeting the goals of national security while stimulating general economic growth through technological innovation. With highly constrained budgets, however, such technology investments must be based on a clear prospect of tangible benefits that can be monitored and measured effectively.

In recognition of this need to carefully select technology investment programs based on measurable results, the Round Table was convened to explore three key issues:

- How can agencies with applied technology programs best select where to invest public resources?
- How should the government seek to measure the results of its investments in technology development and application?
- What lessons have been learned about managing the intersection of economic growth, national security, and the pursuit of other national objectives?

² **Review Note:** This research included scientific research supported by the National Science Foundation and the National Institutes of Health, as well as government support of applied research and technology development for military, space, and health-related purposes. Such investments enriched the civilian economy through spin-offs and technological spillovers, especially in the areas of microelectronics, computer hardware and software, and pharmaceuticals and biotechnology.

The Round Table reviewed and sought to improve ongoing national efforts to create a framework for assessing and measuring the results of national technology investments. Participants included many authoritative observers of the economics of technological innovation. They represented the perspectives of academia, industry, and the federal government. Discussions centered on different types of quantitative and qualitative measures and their applicability to different kinds of government technology investments. Within this framework, participants explored potential linkages between research, innovation, and long-term economic growth.

OVERVIEW OF ROUND TABLE PROCEEDINGS

Keynote Address

Dr. John Gibbons delivered the keynote address. He first described the political and economic factors that affect science and technology policy, and then discussed the importance of government support in this area. Dr. Gibbons noted that many in Congress question whether the government should be investing in certain types of science and technology they regard as outside the province of government and are, in fact, seeking to cut many types of federal science and technology (S&T) funding. In the face of such questions, the Clinton administration is not only reaffirming the government's historical support of fundamental science, but is seeking partnerships with the private sector for certain kinds of applied research. The administration recognizes that it must have clear measures, or metrics, for choosing investment programs, for measuring the benefits of those programs, and for demonstrating those benefits to the American taxpayer.

Session One: Decision Criteria for Technology Investments: Understanding the Rationales for Commercial and Dual-Use Technology Programs

The first Round Table session sought to *identify indicators that may be used to help government decision makers target publicly financed investments in ways which can generate high social rates of return*. The participants considered both *ex ante* criteria for technology investments and *ex post* methods of evaluation. The discussion addressed several questions, including: What are the best criteria for choosing public technology investments? How can we identify federal S&T investments with a high probability of resulting in commercially viable technologies? What can we learn from the experience of other nations, states, and private industry about identifying areas for investment with a high potential for social returns? And, finally, how can performance measures be used,

along with sunset provisions and other limits on investment, to tell government decision makers when to terminate public investments?

Session Two: Tailoring Metrics to Economic Policy Objectives: The Case of ATP, MEP, and the NIST Laboratories

The second session drew upon the programs and experience of the National Institute of Standards and Technology (NIST), within the Department of Commerce, as a surrogate for all commercial technology programs. The goal was *to identify the strengths and weaknesses of the tools available for assessing public technology investments, and to determine how to apply different sets of performance metrics to different types of commercial technology projects*. Questions addressed included: What do we know, and when do we know it? What sorts of impacts are we trying to measure? Are these the right ones? What are the uses and limitations of the quantitative and qualitative measures we currently employ? When are quantitative measures inappropriate and misleading, and how can qualitative approaches be made more rigorous and broadly applicable? Given that the outcomes only become apparent in the long term, what sorts of short term and interim measures are appropriate?

Session Three: Metrics for Multiple Policy Objectives: The Case of TRP and Dual-Use

The third Round Table session used the Defense Department's Technology Reinvestment Project (TRP) as an archetype for understanding the issues to be considered when making dual-use investments to benefit national security by leveraging the commercial industrial base for defense applications. It addressed the following issues: What is a dual-use technology? What is the role of dual-use programs in promoting a more robust national security? *How can national security benefit from dual-use technology investments and an integrated commercial and military industrial base?* How could such integration lead to more affordable weapons systems? What do we know about simultaneously managing defense needs, commercial environments, and economic growth? Are there lessons to be learned from dual-use that will benefit public investments for other national objectives such as health, energy, the environment, and education?

The following sections of this report provide detailed descriptions of the Round Table proceedings.

SUMMARY OF KEYNOTE ADDRESS

Dr. John Gibbons
Assistant to the President
for Science and Technology, and
Director, Office of Science and Technology Policy

Dr. Gibbons began by noting the timeliness of the Round Table, given the current debate in Congress about the role of government in American life and, indeed, of public investments in science and technology. In his view, many conservative Democrats and Republicans alike see the government as obtrusive and accordingly are focusing, almost single-mindedly, on removing government from our lives. The concomitant goal of balancing the budget in a very short time only lends impetus to the push to drastically reduce government support of science and technology.

The Clinton administration has, from the outset, supported deficit reduction and has made great strides in that regard, Gibbons explained. But the administration is also seeking to maintain an investment strategy that complements deficit reduction, in order to create the potential for returns on investment that more than justify controlled deficit spending.

There are those in Congress who would draw a distinction between science and technology, and support federal assistance to basic science while withdrawing support from technology development. Dr. Gibbons stressed that sharp distinction between the two domains are not supportable, each builds constantly on the gains of the other. Moreover, Dr. Gibbons noted, some budget reduction proposals include dramatic funding reductions not only for technology, but also for science. For example, about \$200 million of the \$1 billion that Congress has proposed rescinding from the 1995 budget comes from scientific programs. Half of that is from the Department of Defense's support of computer science, math research, and engineering education at American universities. Neal Lane, the director of the National Science Foundation, has been told to plan for a budget cut of as much as a 20 percent in the years ahead by the Chairman of the House Budget Committee, Representative Kasik.

The administration, in contrast, wants to continue the federal government's historic support of fundamental science, as well as its recent support for applied science and engineering. Given the political and economic realities of our time, it is also concentrating on building partnerships with industry, universities and community colleges, and state and local governments to develop technologies that offer substantial benefits to the economy as a whole. Many of these activities are in jeopardy, according to Dr. Gibbons, who cited the following examples:

- *The Advanced Technology Program (ATP)*. This program is run by the National Institute of Standards and Technology (NIST). It is industry-led, cost-shared, and projects are selected competitively strictly on the basis of merit.
- *The partnership for a new generation of vehicles, also known as the Clean Car Program*. The goal is to develop, within 10 years or less, a new vehicle that gets three times the mileage currently attainable—without sacrificing performance, quality, safety, and affordability.
- *The Environmental Technology Strategy*. This recently released strategy calls for government-industry partnerships for innovation in the U.S. environmental technology industry both to clean up pollution from the past and also to prevent pollution in the future. This strategy focuses both on fulfilling domestic needs and on exporting into a rapidly growing world market.
- *The NIST manufacturing extension partnership*. This program is a grass roots network of industrial extension services that can help small manufacturing firms compete more effectively with modern manufacturing equipment and practices.
- *The DoD Technology Reinvestment Project (TRP)*. This program is designed to encourage the commercial development of technologies that are also critical to our military. Low-cost commercial manufacturing practices and economies of scale resulting from commercial production would make these technologies much more affordable for military users.
- *The National Information Infrastructure*. This program supports R&D that would continue our nation's leadership in high-performance computing, and improves the accessibility of that technology.
- *The Climate Change Action Program*. This program promotes, among other objectives, energy efficiency and the use of renewable energy to conserve resources and limit the impact of human activities on the global climate.
- *Industry-led Cooperative Research and Development Agreements (CRADAs)*. These agreements, which have multiplied tenfold since the beginning of the

administration, help move important new developments toward the commercial marketplace, with benefits in such areas as health care, transportation, and home design.

Dr. Gibbons stressed that programs such as these have been successful both in the United States and in other countries, but that the public and the Congress know little about them. Thus he suggested that the participants educate the public and Congress about such programs in numerous and varied forums.

Dr. Gibbons also stressed that in supporting these programs the government must answer clearly the following questions:

- Why is government investment in technologies that benefit us all indispensable?
- What has changed in the world to make these investments more important than ever before?
- What has been happening in the world economy that now underscores the imperative for us to join other nations that have successfully joined public and private interests?
- How can we know whether we are really getting the results we expect and desire from our publicly funded technology investments?
- Can we devise measures to guide our decision making as we select projects, monitor their progress, and evaluate their ultimate success or failure?

In concluding, Dr. Gibbons focused on the need to identify ways to measure the success of government-supported technology programs. He cited, as an example, recent research at Georgia Tech which evaluated the experiences of more than 200 firms that had cooperated with federal laboratories to develop new technologies in a recent 5-year period.

- 89 percent said that the interaction was a good use of company resources and that the interaction yielded a net benefit to the company.
- 22 percent of the cooperating firms already had a new product or a process or service as a result of the interaction.
- 38 percent more had a new product under development, and another 23 percent had improved an existing product.

Dr. Gibbons cited job creation as another possible measure but noted that the Georgia Tech research had not indicated direct success in this area. He encouraged Round Table participants to share their own experiences and knowledge in discussing

how to select technologies that are worthy of government investment, how to measure the results, and how to anticipate outcomes.

Session One
**DECISION CRITERIA FOR TECHNOLOGY INVESTMENTS:
UNDERSTANDING THE RATIONALES FOR COMMERCIAL
AND DUAL-USE TECHNOLOGY PROGRAMS**

Session one addressed *ex ante* criteria for choosing technology investments, and *ex post* methods of evaluating them. This section first summarizes the main points of presentations given by government and industry participants, and then highlights key perspectives that emerged from the Round Table discussion.

***EX ANTE* CRITERIA FOR TECHNOLOGY INVESTMENT**

Science and technology policy comprises a key part of the Clinton administration's platform for economic growth and industrial competitiveness. The recent shift in the composition of Congress, however, has resulted in a broad-ranging debate about the appropriate roles of government—a debate that is likely to continue over the next year and a half. During that time, national science and technology policy is sure to remain an issue. The Clinton administration will most likely argue, as do most economists, that there are particular areas in science and technology where national government clearly has a role, especially where the government invests in technology for the public good, and where technology investments for its own missions work to improve the national technology infrastructure, or provide knowledge which can be exploited by the commercial sector.

Perhaps the critical issue to be resolved in the anticipated debate is represented by the phrase “picking winners and losers.” This phrase has been used to connote a process of advocacy by selective investment that critics believe government should avoid. But historically this process has been unavoidable in the formulation of public policy. Government chooses winners and losers every day by virtue of its routine operations in making tax and regulatory policies, in selecting key mission areas, and in making R&D decisions. Arguably, “picking winners and losers” is not only unavoidable, but essential to good government. If so, the issue is not whether or not the government should make choices, but how to make those choices good ones. The bases for making sound choices

in science and technology investments, termed *ex ante* decision criteria for the purposes of the Round Table, are not always apparent, and can be extremely complex.

Policy Considerations

The decisionmaking processes at the policy and program levels are distinct but quite related. The policy level is concerned with the national technology system. In total, among all government and private sources, the United States spends approximately \$160 billion a year³ on research and development. To best accomplish the nation's various science and technology goals, decision makers try to allocate these investments across a host of different missions in interrelated program areas within the broad science and technology community. At this level, *ex ante* decision tools are aimed at improving the mix of investments in science and technology programs

At the program level the issues of *ex ante* selection are concerned with the allocation of resources to particular competing approaches. In particular, among many competing approaches to solving a problem, or among many promising technology applications, how should one choose, in advance, those to support with federal funds?

Economic Considerations

In the last decade the commercial marketplace has become an extremely aggressive environment. The United States has lost its leadership in various industries and is faced with threats to its leadership in numerous others, although there remain many very healthy and competitive industries in the United States.

As one important consequence of this situation, companies have been reducing funding for long-term research and focusing on short-term development.⁴ Such changes can be found in many large commercial laboratories, such as those at AT&T, General Electric, and DuPont. Almost without exception, such organizations today are much narrower in their investments, more focused on the company's business, and more closely linked to the firm's operating divisions. Industry is focusing its R&D investments almost exclusively⁵ on products and processes that are appropriate to individual companies and

³ **Review Note:** The annual expenditures in the U.S. from all sources on R&D are closer to \$180 billion per annum.

⁴ **Review Note:** This comment and the preceding paragraph make the United States appear as if it is on its last legs in the R&D arena, an implication that is patently not true.

⁵ **Review Note:** Perhaps this should be "more narrowly" rather than almost exclusively.

are therefore expected to provide a return on investment to the firm which will help maintain or regain its competitiveness.

Government, on the other hand, has traditionally invested in the general science and engineering base at universities on the one hand, and in mission-related technologies on the other. Government decision makers have believed that the results of such public sector investments would inevitably "spin off" to industry and would thus provide a resource for commercial purposes. Therefore, in the U.S. there has never been a purposeful, technology investment strategy to promote the general economic welfare, national economic growth, and international competitiveness of American firms.⁶

In today's world such a laissez-faire approach to linking public sector investment to general economic benefit is simply not enough. It has become very important, at the policy level, to rethink federal R&D allocations as part of a strategy that attempts to balance traditional mission investments in defense, health, energy, and space with national technology needs in the general economy. This balance should continue to include a commitment to funding basic science and engineering research in the university base.

Toward that end, the Advanced Technology Program (ATP), administered by the National Institute of Standards and Technology (NIST), is targeting commercial infrastructure technologies that are long-term and high risk, and that firms are unlikely to undertake themselves because of issues of appropriability to the firm and uncertainty of result. ATP investments end prior to the point of product development. Firms must themselves fund production, manufacturing, sales, marketing, distribution, and advertising. The ATP targets investments toward overcoming fundamental technical barriers so that the marketplace can work more efficiently.

Selection criteria for ATP projects include such factors as the technical soundness of a proposal and its attractiveness to the R&D community, the potential for the proposed project to provide broad-based economic benefits for the U.S., consideration of the ability of a proposal to take a technology downstream into the marketplace, and the level of commitment, experience, and qualifications of the proposal team.

⁶ **Review Note:** The United States did invest in breeder reactors and supersonic transports, so there have been purposeful technology investment strategies in the past, contrary to this assertion.

ATP funds are allocated on a strategic investment basis, whereby approximately \$150 million is allocated over a 5-year period for each technology focus area. Strategic areas are chosen based upon advice from industry and a consideration of the following types of issues:

- What is the economic potential of funding a particular technology area?
- Where are the good technical ideas?
- Where is the commitment from the industry, not just to share the cost of the program, but to take it downstream?
- Where are the places where federal investment will have the highest leverage?
- How do we ensure that we do not duplicate private sector investments?
- How do we ensure duplication does not occur with other agencies around the government?

Because the objective of the ATP is to achieve national economic goals, and because that requires industry to take technology to market, the role of industry is central to the ATP technology area selection process. Every area funded begins with a concept in a company or in a group of companies, not with the government.

Requirements of Military End-Users

In contrast, the Department of Defense invests in dual-use technologies based upon a clear and compelling need as judged by military end-users. In choosing projects for investment, defense decision makers assess the state of the relevant technology, the likelihood that an investment will truly accelerate the pace of maturation, and the impact on defense of the new capabilities that may be achieved. In addition, defense technology investment decisions are based on an in-depth understanding and characterization of the supplier industry. What is the inherent industrial capability to make certain investments? What resources are required to make a difference or to achieve specific goals? What investments will suppliers most likely make, and where will they produce the resulting product? The decision to produce offshore or onshore has significant national security implications.

The Potential for Government-Industry Partnership

There is a strong consensus that government has played a key role in developing microelectronics and will probably continue to do so as the technology evolves and new

inventions are created. Although investments in microelectronics research and development originated in industry, a great deal of critical R&D was sponsored by government. Originally termed "molecular electronics," this technology emerged in the 1960s, as the result of an effective government partnership with industry.

In the 1980s, a major shift to offshore microelectronics production, a concern for profits, and a regeneration of microelectronics technologies led to a renewed government commitment to bolster the nation's competitive position. This was expressed in a variety of programs, not all of which were completely successful. SEMATECH (Semiconductor Manufacturing) is an example of success, while the VHSIC (Very High Speed Integrated Circuits) program provides important lessons regarding the need to carefully target government funds to intended recipients.⁷ More recent efforts in federal support to microelectronics, particularly in the area of flat panel displays, are too embryonic to judge.

SEMATECH. Some argue whether it was a correct decision to proceed with SEMATECH, and others see the venture as an example of government making sound technology investments in the microelectronics business, which is the underpinning of the information age. The original object of this program was to improve the U.S. manufacturing capabilities for a specific class of semiconductor firms, with some focus on providing the capabilities to firms that were suppliers to the microelectronics industry, particularly those that developed and manufactured the equipment used to produce microchips. This program enjoyed bipartisan support, primarily because it was coupled to a government mission—that of national security. Even so, it was widely acknowledged that SEMATECH addressed larger issues than national security and, issues concerning the nation's future economic strengths in areas which are critical to information technology.

VHSIC. In the early 1980s, DoD invested approximately one-half billion dollars in the Very High Speed Integrated Circuit (VHSIC) program. Much of that money went to the aerospace industry, for whom microelectronics was not their core business.⁸ As a

⁷ **Review Note:** VHSIC experiences point out the pitfalls of trying to develop cutting-edge technologies in a relatively isolated military industrial sector with insufficient links to and competition with commercial firms.

⁸ **Review Note:** Is it true that only aerospace firms benefited from VHSIC, or were some of the firms really military contractors such as Harris Corporation, and defense divisions of large firms such as Texas Instruments and IBM?

result of its structure, this program generally failed to channel government funding to the key suppliers of microelectronic circuits. Although the program achieved some very important advances in the design of microcircuits, and many of the microcircuit design tools that exist today can be traced back to these investments, the program nonetheless failed to meet its objective of improving the capabilities of the microelectronics supplier base.

Flat Panel Displays. The recent decision to proceed with government support for a flat panel industry has been controversial. The United States lags behind Japan in the development of this technology that emerged from a joint investment between Japanese government and industry. In the last few years flat panel displays have been recognized as a critical technology for national security. Proponents say there is a compelling need for the military to have access to both the on-shore design and manufacture of displays; that Japan enjoys the advantage of early development for which the government can compensate; and that the flat panel design and manufacturing are of fundamental importance for the development of other microelectronic capabilities. Others have suggested that the first mover may be at a disadvantage because the technology is evolving in new directions beyond the particular one being produced today.⁹ The United States flat panel industry is best described as weak, while off-shore competitors are very strong. It remains at issue whether or not the advantage of foreign competitors can be overcome through government and private investments.

Composite Materials. Composite materials are of vital importance to the military. The fate of the composites industry, however, has been historically tied to large military procurements such as the B-2 bomber. When such programs were terminated or curtailed after the end of the Cold War, the market demand for composites dropped by more than a factor of four, leaving the industry scrambling. In addition, the commercial sector for composite materials, particularly the high end of the materials, was being driven offshore by the sporting goods market, which the Asian countries captured in the 1980s.^{10 11} It

⁹ **Review Note:** Is this really a practical possibility? Japan's investment in flat panel displays is huge. Where would a comparable investment in the U.S. come from? Perhaps a more persuasive argument is that Korea and Taiwan could work together in the business and undermine Japan's (primarily Sharp's) market power.

¹⁰ Sporting goods constitute a very profitable segment of the industry. A \$200 tennis racket contains only about \$15 of composites, yet the racket is marketed based on the composites.

¹¹ **Review Note:** Is it not true that Japan's production of composites for commercial aircraft (e.g., the Boeing 777) is rather important to their market share?

was clear that defense requirements could no longer sustain the industry in a way that would satisfy critical defense needs. This situation led to a search for alternate markets for composites, both in and out of the aerospace business. Under the Technology Reinvestment Project (TRP) a program was therefore established at Pratt and Whitney to rapidly insert composites into turbine engines. As a result, new sources of demand for composites relevant to defense are coming on-line. TRP has also supported investments in construction which may be applied both to military purposes and to earthquake proofing of bridges in California.

Commercial Sector R&D Investments

In the commercial microelectronics and computer industries there is no longer any real vertical integration.¹² Each firm makes investments in those areas where it has a particular expertise or "core competency." Where a firm does not have in-house expertise it instead depends on other companies. For example, a firm may have expertise in graphics, microprocessors, digital media, parallel processing systems, and user interfaces. But it might lack expertise in complementary technologies such as semiconductor processing, display and storage, applications programming networks, consumer electronics content, or media distribution. To complete the set of technologies necessary to compete and do business, it becomes necessary to form partnerships with a large number of other companies from a variety of technological areas become necessary.

The investment environment in microelectronics is therefore extremely challenging. Even though it is a very vibrant industry, this is also extremely competitive, and that competitive environment puts constant downward pressure on margins. As a consequence, over the last 10 years there has been a reduction in the percentage of revenue devoted to R&D, and this appears to be a trend.

Short product cycles are another source of pressure. In the microelectronics industry, 2 years is about as long as a product cycle can last if a firm is to have continued success in the marketplace. And the turnover in products is staggering—typically, over 50 percent of a firm's revenues come from products that take less than eighteen months to develop. Old products simply become obsolescent and unmarketable.

¹² **Review Note:** There still is vertical integration in such markets in Japan. Also, firms in the United States such as IBM are certainly to be regarded as vertically integrated.

Most firms in the microelectronics industry are placing less emphasis on basic and applied research and more emphasis on the development of products and processes for the marketplace. Even in areas of core expertise firms tend to rely on other parties, primarily universities, for longer range research. This does not mean an absence of all long-range activities, for example such undertakings as technical and research conferences for company developers and researchers. Because the industry is fueled by a constant stream of Ph.D.s from university research projects, there is a need to publish at these conferences to attract new talent. In fact, some firms explain some of their most important secrets at public forums just to attract bright new employees—a critical requirement if a company is to continue to prosper.

Therefore, in the commercial electronics and computer industries most private sector technology investments are short term, and the sizes of these investments are shrinking. So far, university partners have enabled firms to find and take advantage of some breakthroughs in fundamental science and technology, primarily at the systems level.¹³

Advances in component technology are continuing—at least, today—at a frantic pace, primarily among suppliers. Many of these suppliers are often very small companies, but because the pace of development in this area is part of what drives short product cycles, successful firms in many cases depend on very small companies for critical new component technologies. In essence, suppliers represent a form of R&D investment, although to an outsider it may appear as vendor relations, not R&D investment.¹⁴

In return, willingness to become an important supplier for large companies has so far enabled many small and start-up computer and electronics firms to become some of the industry's most innovative firms. Stable customers on the part of large firms therefore allow small firms to obtain the necessary cash flows to make investments they need to fulfill industry expectations for new products, processes, and technologies.

In the commercial microelectronics industry, partnering with other firms to spread the risk of investments is also common. For instance, Silicon Graphics has a partnership

¹³ **Review Note:** It is important to note that much of the money for university research comes from the government, so that companies are relying on the government for a considerable portion of the basic research they consume.

¹⁴ **Review Note:** Important point.

with Time Warner to develop interactive TV, a partnership with Nintendo for graphics technology and video games, and a partnership with AT&T for video on demand servers and network technology. These are big projects that are strategic gambles—attempts to open new areas and new markets.

Defense Sector R&D Investments¹⁵

Defense companies, particularly those attempting to shift from defense to commercial markets in the face of DoD downsizing, encounter a vast difference in commercial firms' culture and approach to business. Defense firms understand the defense market from the perspective of their long-term customers. They know how defense markets act and react to changing environments. On the other hand, defense firms' executives freely admit that they have limited understanding of commercial markets and innovation processes, because they lack practical experience.

Nevertheless, defense firms are attempting to enter the commercial marketplace, albeit slowly. The pace of transformation from defense to commercial markets is evidenced by the level of R&D spending by large firms, where the majority of investments still target the development of systems for DoD. On the other hand, as defense budgets go down it becomes harder and harder for many defense firms to justify continued expenditures in shrinking markets. In particular, the metrics for determining the allocation of new investments among defense and commercial opportunities are difficult to derive and not clearly interpretable. For instance, should internal budgets be proportional to the annual defense budgets, taking proportionate reductions every year? Or, should investment follow a firm's 5-year projection of bookings? While the projection of bookings may be the best criterion from a theoretical point of view, unfortunately there is widely held belief in industry that long-term projections are not reliable.

Inevitably, defense firms behave like commercial firms when it comes to their customers. There is strong coordination with military customers which is built upon years of experience with military procurement practices and requirements.¹⁶ Commercial

¹⁵ **Review Note:** One reviewer observed that the paper is too strongly oriented towards defense and that this section should be completely omitted. The rationale is that inclusion of the apparent defense bias implies that a dual-use strategy depends on defense firms entering into commercial pursuits. This is not a highly likely outcome; in fact, defense firms seem to be surviving by combining through mergers and acquisitions.

¹⁶ **Review Note:** It is more likely that dual-use will succeed when the military begins to procure more from the dynamically competitive commercial sector.

investments by defense firms, on the other hand, are largely experimental and “buffered” against failure by playing against successful defense technologies. This is a dual-use strategy that attempts to leverage defense expertise which may have a high commercial payoff.

Another strategy in the defense business is to compete with other defense firms on the basis of weapon system affordability and capabilities. This is done by taking hardware/software systems already supplied to the military and making them more affordable—similar to competition in commercial markets among innovating firms competing on the basis of price for market share. Examples of such commercial endeavors in the dual-use of technologies are found in the telecommunications and medical systems areas, in transportation and movement of goods across the world, and in imaging systems.

Insofar as a defense firm is willing to take the plunge into commercial markets, such decisions are made on the basis of anticipated profitability. In many cases technology investment decision making relies 99 percent on this “simple” criterion. This reflects the emphasis on short turn returns on investments held by industry executives with a primarily financial view of the world.

The drive for short-term returns in the private sector results in a focus on investments that can yield immediate returns. An important role for the government is to enable the private sector to take a longer term view by defraying some of the risk associated with extended time horizons. Such government efforts should stimulate, not simply supplement, private sector investment. This will make it easier for executives in industry to justify making their own investments where there is a potential for longer term payoffs.¹⁷

The Role of Peer Review

The peer review issue is not whether we should give money to science and technology. It is concerned with the distribution of resources to particular scientists and engineers or particular projects. How do we evaluate and judge what our science and technology projects should be? How do we evaluate their performance? We have to make judgments about the returns we expect, and this is extremely difficult *ex ante*.

¹⁷ **Review Note:** This paragraph implies that government dual-use policy is oriented towards bringing defense firms into commercial markets, which is not the case.

Role of Intuition. Despite all the attempts at quantification in science and technology, we have historically used qualitative indicators to make most funding decisions. That is, we become imprecise rather than precise, so all the positive virtues that we normally think of as scientific become hard to recognize. Of course, anyone who has studied the nature of the scientific enterprise knows how important intuition is to the pursuit of scientific objectives. So, in fact, the image of scientific precision and rigor is a bit overdrawn. Many of the greatest leaps of science have been leaps of intuition that have not been based on line-by-line-deductive reasoning. Such outcomes are impossible to predict. They remain to be explained retrospectively.

Peer review, which must account for intuition as well as prediction, is an imperfect and often qualitative approach to making judgments about the likely outcome of investments in scientific research, but it is the best available method for the *ex ante* allocation of resources. If we are aware of the biases inherent in a peer review process, we can try to compensate for them. Those who do peer review well are aware of bias problems and attempt to correct for them.¹⁸

Bias Effects. Two primary types of bias occur in peer review. The first type is the *fad effect*. There are fads in all disciplines. These are certain subjects that become very popular and generate sizable literature. When a peer community is asked about the scientific interest of a proposed project, there is a bias that what is interesting is what a large number of investigators are pursuing. If there are many investigators pursuing similar research, then there are many voices to say, "This is really interesting," without much consideration of the potential social return from the particular enterprise.¹⁹

Without a way to relate scientific and technological endeavors to prospective social returns, peer review entails a certain degree of myopia. For instance, in the 1970s it was very hard to obtain research support for investigations of technology and technological change from the NSF economics program. Since no one was doing such research, it was presumed not worthy of investigation. Similarly, we recognize today how important environmental externalities are to determining the quality of life. Yet 20

¹⁸ **Review Note:** Important point.

¹⁹ **Review Note:** Are social returns a proper consideration for scientists and technologists?

years ago this was not a subject in which there was much economic research, and it was therefore hard to get projects approved through the peer review system.²⁰

A second related bias that occurs in peer review is the *fraternity effect*. In this case investigators act to positively reinforce each other's work or interests. In the field of economics, it is interesting to note, there are strong fraternity effects in some subspecialties and strong property rights effects in others. Property rights effects occur when peer reviewers working in an area respond to a new proposal by indicating that the work is already being solved by someone else. Those in the fraternity work to prevent others from entering and disturbing their investigative turf. The sociologies of subgroups within a field differ markedly, and can bias the outcome of peer reviews in ways that are obscure to the outsider.

Good peer review, therefore, takes known biases into consideration and tries to protect against them. For instance, program officers in economics have long had open discussions of bias problems and have studied various subgroups within the discipline. When the peer reviews are received, the program officers take these biases into account and try to offset them.

Ex post vs. ex ante evaluation. It is important to recognize that project evaluation is nothing more than cost benefit analysis applied to *ex post* assessment. We do a lot of cost-benefit analysis, and it is all *ex ante*. Rarely do we return after a project is complete and ask if estimates about the costs and the benefits were any way commensurate with what actually resulted. *Ex post* assessments have the function of going back and reviewing the returns, the costs, and the benefits of a project. This is not only to satisfy intellectual curiosity. It is important to our understanding of the role of assessment.^{21 22}

Ex post assessments provide a much better view about how well we are doing in resource allocation, designing incentives, and *ex post* justification. In particular, we must become aware of areas where there may be systematic deviations of our expectations from realization. If we can identify systematic errors in judgment, then we can attempt to undo the systematic biases.²³

²⁰ **Review Note:** This is not altogether true. In 1975 both the Council on Environmental Quality and Resources For the Future were very interested in this subject.

²¹ **Review Note:** Important point.

²² **Review Note:** As written this paragraph is inflammatory for the scientific community.

²³ **Review Note:** Good statement of the issue.

For instance, NSF has, over the years, tried to learn whether there is a bias against young scholars or old scholars. There have been allegations in the past that young scholars have trouble breaking into the group of sponsored researchers. That is a question that is amenable to statistical analysis. You can determine the rate of entry of young people, determine when do they come in, and what their records are at that time. As it turns out, the evidence is that there may be discrimination against older scholars, rather than younger ones. NSF may have become so concerned about younger scholars that peer review now is biased against older scholars. Furthermore, the people who have the time to sit on the peer review panels tend to be younger people,²⁴ and they tend to take the view: “What theorems have you proven in the last three hours?” If the answer to that is, “under three,” the view is that you, obviously, have been losing your marbles and no longer warrant continued support.

One must also try to be careful about when qualitative judgments are likely to be superior to quantitative data, and when they are likely to be inferior. If one sits on an admissions committee, such as those found in universities, there is a widespread belief among the members that they have an ability to bring to bear qualitative judgments on what is likely to make a successful student—all of us have an enormous amount of credence in our own abilities in this respect. But that is something that is amenable to statistical verification. The few studies that have been done seem to suggest that admissions committees have absolutely no ability to make judgments. That is to say if you look at performance based on what would have happened if you used a regression model, you do better than with an admissions committee. An admissions committee’s judgments add noise to the selection process. This stands as a caution in all of our confidence about the value of qualitative information and our strong ability to make good and sound judgments.

²⁴ **Review Note:** Is this really true? Are review panels usually composed of younger people? Or is this a function of the particular discipline?

Qualitative Assessments of Research Results²⁵

Before a project is started, there are assumptions that underlie its expectations. These include assumptions about how the market is going to develop, and assumptions about how profitable the business is going to be. But *ex post* evaluation occurs after the initial investment when decision makers look back and ask, “Did our investment—which the corporation paid for as part of its total bottom line and profitability—put us into a reasonable position?”²⁶

The benefits most often looked for and talked about are major breakthroughs that will lead to major products and put a firm ahead of the competition. But those may not be the most important benefits. A firm needs the ability to catch up with companies or institutions that make the breakthrough first. No matter how a firm invests in research, it is not going to make all of the breakthroughs. This means a firm needs the ability to assess technology from wherever it comes, and judge what will work. It is equally valuable to know what will not work, to avoid putting development dollars into dead ends. A firm needs to be a wise procurer of technology, and a research team can help, even if it is not its own technology supplier. A research team can serve as internal consultants to assist in sorting through university research.

Industry’s technology investments are intended to develop products or services on which the company can make a profit, and this profit can be measured. Profitability depends upon the response of customers and the response of competition. It is very important to be able to assess revenue streams to decide where to make technology investments. A company’s report card shows up every day in *The Wall Street Journal*. R&D investments are a part of the equation. The question is this: Of current revenues, how much should be returned to shareholders and how much should be put into R&D, and where? How much money really goes into technology versus development versus engineering and product versus process versus infrastructure?

²⁵ **Review Note:** This whole section refers to *ex post* evaluation of private R&D. The Round Table was about metrics for public and cooperative investments. This gives the impression that public investments can be evaluated in the same way as private ones. Also, the NIST approach to *ex post* evaluation is completely left out here, even though it is the best we have in the government for public sector technology investments.

²⁶ **Review Note:** There is a need to make the distinction between science and technology here. The Round Table was concerned with technology. *Ex post* assessments are already difficult enough in the technology area, and are even more difficult (if not impossible) in the area of science (basic research).

Ex post methods of evaluation are really a continuation of the *ex ante* methods. These *ex ante* methods are frequently referred to as a business case—a detailed analysis of the various expenses, including capital expenses, revenues, and the eventual profits. In any well-run organization, the business case for the whole project has to be undertaken before the project starts. It should be updated regularly, and there should also be an analysis when the project is complete.

When is a project complete? Some would say: When the design is turned over to the manufacturer—an answer that is obviously incorrect. Some would say: It is when the first product is sold to a customer—a response that might be correct. Some companies say: It is when you first break even on the total project.

For ongoing assessments, the judgments of peers, mostly within the company, can be used. It is also possible to solicit the judgments of peers outside the firm as to whether the quality of the work you are doing is good. Firms should also review what were their starting points and ask themselves: “Are they still achieving the attractive market results that they thought might be there?” “Is tactical performance up to snuff?” “Is it going to allow the firm to achieve the market share that they thought they were going to get?” “Are they on schedule?” “Is the project cost going to overrun?” One should therefore look continuously at the relevance of what one is doing in the business because this will change as business and technology prospects change. As part of this ongoing process of evaluation, one therefore heavily depends upon the informed judgment of “smart” people. As part of these continual assessments one must also face the issue of whether or not it would be prudent to terminate a program rather than continue it.

Finally, the degree of interaction between the firm’s research staff and its development staff should be continually reviewed. Lack of effective communication here suggests that the project may not be on track. It also means that the chance of taking research results and turning them into useful products or services is greatly diminished.

Econometric Assessments

Econometric measures of the results of technology investments are quantitative, but abstract. Econometric analysis is based on theories of economic growth which originated in the 1950s, when Robert Solow and Moses Abramovitz, among others, tried to evaluate the determinants of the rate of productivity growth in the U.S. and other major economies. They discovered a mysterious residual—a large fraction of growth which appeared to be unexplained by capital investment, labor, or other obvious sources.

Economists searched for explanations of this residual, considering such factors as education. Solow suspected that the primary determinant of the residual was innovation, and attributed its cause to "technology" or "technological change." Economists consider R&D investment to be a source of this technology residual.

It also appears that the technology residual is associated with "spill-overs" to firms other than the initial innovator. The economics community strongly holds that R&D investments not only benefit the innovator, but also lead to the creation of so-called public goods. The innovations of one firm lead to indirect benefits for other firms.

Economists also hold strongly that traditional market incentives will not necessarily yield a rate of return to innovators which is as great as the one for society at large. R&D tax credits, for example, are justified by the Council of Economic Advisors as a means of increasing the rate of return to entice firms to make investments which can have broad social benefits.

Econometric analysis, as performed by economists such as Zvi Griliches at Harvard, includes a search for the spill-over effects which can help explain overall productivity growth, including the growth residual. Analysts seek to understand, for example, how spill-overs may be employed as important policy tools. Econometrics seeks to reveal how activity in one industry or firm affects other firms and other industries.

One of the strengths of the econometric approach is that one can, in principle, avoid the selection bias that creeps in when performing case studies. For instance, Edwin Mansfield did a series of case studies which looked at innovation within companies, focusing on investment costs, returns, and the extent to which returns spilled over into other companies. But there is always the possibility that such a methodology will be biased toward winners, because one is studying companies that are known as innovators. There is a danger in the case study approach that one will select *ex post* those companies or research projects with a higher than average return. This leads to an overstatement of the overall rate of return. Econometric analyses which look at the performance of an entire industry, or a whole set of industries, can be more inclusive, by including R&D investments that may not have paid off as well as those that did.

A second strength of the econometric approach is that it can account for spill-overs that are not apparent to the case study worker. Mansfield did a superb job, but he was limited by his ability to see where technology development in one firm affected

operations in other firms. In recent econometric literature, there have been attempts to track spill-overs more widely. People have looked at technology relationships between supplier industries and downstream industries. For example, they have examined patent citations to trace technological links among industries and then estimated the these effects through statistical methods. Ideally, one would like to look at links worldwide, since the technology that is developed in a firm in the United States might be the result of work that was done in Japan or Germany, and vice-versa. Unfortunately, such research has not been done, although considerable work in the United States has tried to take a broader view of spill-overs.

What are some of the weaknesses of the econometric approach? There is always the danger that one will arrive at a correlation and not know if it is meaningful, particularly with respect to the direction of causality. This is particularly difficult with R&D because there is no quick response to changes in R&D budgets in either the output or the productivity of the industry. There are long variable lags between R&D, its effect, and the number of patents or productivity changes that result in an industry. The economics profession has developed many sophisticated techniques for getting around these issues, but at the end of the day there is always the element of doubt.

A second weakness of econometric methods is that they are not of great use to policy makers for reviewing a particular investment. Econometrics is not a substitute for the men and women making wise decisions about which project to fund because such decisions are done on a level which is much more specific. Rather, econometrics is helpful in understanding why it is important to support R&D in general, and in helping to determine if the overall magnitude of effort is sufficient.

There are important technical problems in making econometric estimates. For instance, it is particularly difficult to measure the amount of R&D that is being done because reported R&D data may be missing a lot of the action. It is also difficult to measure inputs and outputs. As an example, until some years ago the output of the computer industry was imperfectly measured. It was assumed that the price of computers remained constant over time. So measuring productivity in the computer industry was, obviously, a flawed exercise. The Department of Commerce then went into a major project to construct new computer price indexes, using "hedonics"; that is, trying to assess the characteristics of the computer, the number of MIPS, the size of the hard disk and so on. As a result, statistics reveal considerably more output and productivity growth generated in the computer industry than before. In a lot of industries price measures are

still poor, and it is hard to capture the return to R&D investments. This is a fundamental problem in assessing overall productivity and performance of the economy, but it is of particular concern for R&D assessment.²⁷

Case Studies

Case studies may be used to help decision makers make better judgments than they might make based on abstract data, and they provide clear evidence for the value of the science and technology enterprise. This point is important because of recent skepticism about the utility of certain kinds of government technology programs. The accusation is not just that the government “builds bad bridges,” but, rather, that government should not be building bridges at all. The question may be asked, “Why shouldn’t government just spend more money on tax incentives, reduce its regulatory role, and let things proceed on their own?” Case studies provide an explanation about how industrial competition operates, and how companies come to succeed in their marketplaces. Case studies are a particularly important part of *ex post* justification. They provide nontechnical people the ability to assess why that it is in the national interest for more beautiful theorems to be proven, and more technology investments to be made.

Case studies also help reveal the role of government science and technology in global competition. The pace of technology has sped up. Most companies are no longer vertically integrated in the way IBM traditionally was,²⁸ and this changes the decision of what is to be developed in-house and what is to be obtained from the global pool of technology. Companies are increasingly dependent for R&D on other firms and universities. This suggests that one role for government is to make certain that public programs contribute to a portfolio of technology that can help companies compete in global markets.

We therefore speak of a “supply base,” which is the set of technological components, subsystems and systems that are available to companies and enable them to produce today and innovate for tomorrow. So one task for case studies is to investigate how government projects contribute broadly to a supply base.

Case studies also support the derivation of general principles of technology investment by comparison across cases. It is not just whether a particular case led to

²⁷ **Review Note:** Good section!

²⁸ **Review Note:** IBM is still one company, although more decentralized than in the past.

more jobs, more patents, etc., but a desire to derive a general set of principles that is involved. This raises the question of the unit of analysis. Do you use a set of innovations or an industry? A series of case studies which centered on the semiconductor industry, for example, led its analysts to emphasize the role of closed markets, of constraints on manufacturing capacity, and of the ability to continue to produce particular kinds of goods, on the industry's ability to sustain technology development.

Case studies also reveal ways in which the approaches to technology development in government and industry are incompatible. Government procurement processes typically take 18 months to award an R&D study that may comprise only nine months of actual research or development, resulting in a technology that is obsolete in 12 months. Some of the important information that case studies provide includes an analysis of such barriers to more efficient government investments, and how to remove them.

The quality of case studies may be uneven. Many are simply non-representative vignettes. Nevertheless there is a lot of good work that can be done in the way of detailed multiple studies and systemic comparisons. An area ripe for this type of work would be comparisons between non-government and government approaches to technology investment with the goal of making the government approach more compatible with the civilian approach so that it can stimulate more rapid technological evolution.

To do good case studies requires that evaluation measures be clearly stated at the beginning and retained throughout the program. Data collection for such case studies must be set up at the beginning and continued throughout the program. There are many examples of government programs where the objective changes quite significantly subsequent to program initiation

In summary, the advantage of a case study methodology is twofold. It provides a method to keep track of the successes and failures of particular technology investments. It provides a way to capture lessons learned. There is some agreement that successful cases provide more information than failures. They allow us to emulate and build upon successes. There may be too many combined effects to assign blame in the case of failures. Case studies provide lessons-learned which can assist with future technology investment decision making and with the management of projects.

ROUND TABLE DISCUSSION

Government Role in Science and Technology

Does the Clinton administration support both science and technology? Several recent studies have looked at the School of Engineering at MIT, which gets 55 percent of its research support from the Department of Defense. The percentage in the School of Engineering at Stanford is about the same. Yet, the latest budget that the administration sent to Congress has a \$300 million cut in the research component of the Department of Defense's budget,²⁹ which will fall disproportionately on university engineering research programs such as these. Is the administration saying by its actions that it supports science but it doesn't support technology?³⁰

Although DoD support for university funding has declined in absolute terms, relative to other cuts in the defense budget it has remained remarkably stable. In a defense budget which is shrinking quite dramatically in real terms the programs and functions that you might expect to be squeezed get squeezed. You can't squeeze salaries since they are fixed.³¹ It is difficult to squeeze people, although that has actually been done over a period of time. So what is customarily done—and, this is true both in the private sector and in the public sector—is to squeeze investment accounts. And that, in fact, has happened.

Over the last 10 years, defense procurements have declined by somewhere between a third and 40 percent in real terms. But the research accounts have been protected. That does not mean that there has been no effect on science and technology from the dramatic downsizing of the defense budget, but it is clear that the research accounts have been treated better than any of the other, obviously squeezable accounts. It is extraordinary that the Department of Defense is deferring buying weapons systems which are manifestly attractive and which enjoy wide congressional support, and yet only took \$300 million out of what is, after all, a \$2.5 billion account, roughly speaking.³²

²⁹ Fiscal Year not mentioned.

³⁰ **Review Note:** This is a nonsense question.

³¹ **Review Note:** This is not true, people can be let go.

³² **Review Note:** This must only represent only the 6.1 basic research account. The overall "tech base" is 6.1 through 6.3A, which is in the neighborhood of \$10 to \$11 million.

As far as industry is concerned, there are shortfalls in the basic research necessary to maintain the generic technology base. But, the biggest shortfalls are not in research, but development. Comparing the U.S. with its competitors in terms of development as a percentage of GDP,³³ the U.S. has a \$40 billion shortfall for civilian industry compared with civilian industries in Japan, Germany, or France.³⁴ Thus, even when bright ideas abound, insufficient resources are available to do their development. Subsequent to development, there is a tenfold requirement for capital and marketing investments to bring developed technologies to the marketplace.

The problem is not that industry is underinvesting in development for the products it is manufacturing. The problem is a declining world market share. Over the past few decades the United States has been losing world market share. There are some markets where the U.S. is just not present.³⁵ A prime example is consumer electronics. If the United States were to manufacture its share of consumer electronics—that is, the amount that it consumes—and if that market share brought with it a proportionate share of investment in development, this shortfall would disappear.

One of the things the United States must consider is keeping the level of basic research and investment in pre-competitive technology properly balanced so that industry is financially able to take this technology and do the development, manufacturing, and marketing. A role for government, if it wants to assist high tech industry, is to get the cost of capital down—not the cost of debt, only, but the cost of capital.³⁶ To do this one must look at deficit factors—high hurdle rates, tax laws that favor consumption over savings, depreciation rates. Without tackling both sides of this equation, the nation is putting money into things that will not be exploited in the United States. In part, this suggests that a billion dollars put into tax relief or tax credits may be better spent than a billion dollars that goes into certain technology programs.

We are in the midst of a major shift in this country in resources being applied to this mid-term, applied-technology business. The visible defense budgets have not

³³ **Review Note:** It is important to be careful with this comparison because it requires one to understand what is in the portfolio to make sense of the investment categories.

³⁴ **Review Note:** It is not clear where the number \$40 billion comes from or how it was calculated.

³⁵ **Review Note:** This is only true in some industries. On the whole the United States market share has been relatively steady.

³⁶ **Review Note:** National Academies studies show that not only is the cost of capital important, but management is just as important.

substantially reduced R&D, but less visible budgets—such as IR&D, which in the past was half that of DoD investments—are down sharply because they are based on a percentage of the business base. In the commercial sector there has also been a shift emphasizing development at the expense of research.

How should government make investments with particular companies or sets of companies whose purpose is to produce spill-over benefits? The fundamental goal for government in technology, in an economic sense, has always been infrastructure—long term risky investments. It has never been short term, to take the product to market.

What are government-industry partnerships all about? The government brings to the table the ability to invest for the longer term to achieve broader based economic benefits. Firms bring to the table the ability to invest in things for their own benefit by taking particular concepts to the marketplace.

There are a lot of theoretical discussions about whether R&D tax credits are a better way to solve the nation's development deficit than direct technology investment programs. In fact, the nation has had R&D tax credits in place for many years. During that time there has been no concrete evidence that private R&D, as a fraction of GDP, rose. In fact it may have been stable or even fallen a bit. There is no evidence that R&D tax credits have done the kinds of jobs that Administration technology programs, such as ATP and TRP, are trying to do. Therefore, while issues concerning tax structures and regulatory burdens are important to industry's decision making processes, targeted technology programs remain absolutely critical. It is a false comparison to say one approach is superior to the other. The entire system is in fact important, and both approaches are needed.

Cost share should be adjusted to reflect risks. There is a need to adjust cost share from the government to reflect the degree of risk in a project. While the 50/50 cost share mix is a popular notion, it is bureaucratic and does not properly adjust for risk. There is a need to adjust cost share to the risk and the time scales involved to make sure that opportunities are available for universities and small businesses to be involved. In some cases this means the willingness and ability to accept matching funds in kind—not, just direct monetary contributions.

DoD has a relatively simple technology transitioning problem since it has a fairly captive customer base. The transition should be much less complicated than it is in the commercial world. Yet DoD has never done well even with its captive customers. The

problem stems largely from the technology community which, almost never thinks from the customer's perspective. Technologists think they know exactly what the customer needs, but they frequently don't talk adequately to the customer. There is a lack of communication. If this is difficult under the fairly easy circumstances faced by DoD, then it is extra difficult in the commercial sector. This deserves a fair amount of study, for instance about Japanese practices. They seem to perform much better in this respect.

Funding the future may mean allocating resources where there is yet no constituency. An essential characteristic of advanced technology programs is that their projects and ideas create the next generation's capabilities. These are areas for which there is not yet a constituency, be it the Defense Department looking at new weapons systems, or be it future commercial opportunities. This is especially critical at the beginning of the resource allocation process where one is trying to set priorities. If one only responds to the loudest voices then important opportunities may be missed.

Can review be used to assign resources across disciplines? For instance, how much you put into astronomy versus how much you put into biochemistry? It is difficult to do cross-discipline comparisons, but there is still a role for peer review, something that might be termed the "incentive effect." Sometimes the research community becomes separated from the user community, so that the ultimate social return isn't identified very clearly by the researchers. In some areas, improvement in the allocation of resources across areas could be enhanced by having peer review from the user communities. For instance, policy-related research is supposed to inform a variety of areas of decision making by the government. There are people in the user community who are customers for the research. If the group of people who bridge the scientific and user communities, such as those in OSTP and CEA who are both researchers and policy makers, could become more involved in trying to make these judgments, this would assist in the resource allocation process. For example, in certain areas of the economy that have shrunk in size, spending is related to their relative importance 50 or 75 years ago. There are other sectors of the economy, like the service sector, which have grown enormously, where we are not spending any money on research at all. If you involved some policy analysts they would point out that we are allocating resources in a way that is not commensurate with the current structure of our economy.

One of the problems encountered when discussing critical technologies is that it is easy to become divorced from the capability that is the desired end-product. For instance, an assessment of Navy expenditures would raise questions about why

investments are being made in basic research in biological sciences, mathematics, and other fundamental domains of investigation. The answer is that the foundation for a particular capability may come from fundamental research into areas such as data compression algorithms or biological sensors.

Industry Role in Science and Technology

R&D and technology development are fixed costs,³⁷ and under competitive conditions that raises the issue: Who is going to pay for the fixed costs, particularly if they are costs not appropriable by the company carrying out the R&D investment? In a previous era, the U.S. economy was far enough ahead of everyone else that companies could afford to do a lot of basic R&D and follow-up work on their own. Many of these investments did not have immediate commercial payoff, but they were sustained by the companies because they operated in markets where they were somewhat protected by their lead in technology. This is no longer the case. Today, most technology companies are in such a competitive environment that they are being pressed to specialize only in technologies that have a very immediate commercial payoffs. Because of the globalization of the world economy, there is, in some sense, an even greater need than previously for government to support technology that has a general payoff or is pre-commercial and does not fit into the pattern required to justify commercial investment.

There is no substitute for smart people making good judgments in the selection process. It is important to recognize that decisions are made not only to start programs, but also to stop them. Unfortunately, the government has a poor record in stopping programs, partly because of the political process, and partly because of a need for honest assessments of markets and opportunities. If we create and exercise an opportunity to curtail ventures that are not going well, then the pressure on the first decision is not as great because corrections can be made. There needs to be more focus on how to assess continually the status of projects, and that means a need to involve industry.

Technology Infrastructure—The supplier base is very important as a technology innovator. Looking, for example, at flat panel displays, the issue is not about inventing a new display, but manufacturing equipment. To move firms into the manufacture of flat panel displays requires much more than just the display research itself. Much of the money that went into SEMATECH helped build manufacturing equipment. A big-ticket

³⁷ **Review Note:** It is not clear why R&D and technology development are regarded as fixed costs.

item that DoD is faced with right now is lithography. The Semiconductor Industry Association (SIA) is looking for a lot of help from the government to keep the lithography business healthy. Without a good lithography business, this nation will depend on foreign sources for its lithography capabilities. In the computer area, infrastructure includes the ability to have design tools. Whether electro-optics, optical electronics, or micro-electromechanical systems (MEMS), there is an infrastructure cost. While technology infrastructure has not necessarily been considered an R&D investment, it certainly affects the products that we want to be able to make.

One must distinguish between in-house and out-sourcing for technology needs and R&D. Because of the change in the structure of R&D and investment in the world community, many firms are using their supplier base to provide technology that they might, otherwise, have pursued in-house. That means that the supplier base tends to be small- and medium-sized firms that are very agile and have new and innovative ideas they can develop very quickly. This suggests that there needs to be some thought about how to leverage federal funds that are spent on R&D in partnerships with small businesses, and how best to reach out to them. In turn, how do we assist these enterprises in understanding what the government needs and how its needs can be satisfied, particularly for dual-use applications?

There appears to be a real gap between the rich opportunities offered by small firms and the financial resources available to them to pursue promising ideas. We do not yet have an answer as to how to fuel innovation by small firms that are idea rich but capital poor. This is true for small supplier firms as well in technologically advanced industries.

Technology must be integrated into the workplace. Eventually, all technology becomes implemented and applied by users. They might be downstream users or equipment suppliers, but eventually there is going to be some employee of some company who is supposed to push a button or turn a knob. Current technology policy, occasionally or often but not consistently, is building on the best practices of involving users in the design of technology, making sure that we consider embedding training and so forth. This is an explicit recognition that, for a long time, there has been a tension between the worker community and a technology community. Integrating work and technology is not a new goal for technology policy. The notion of concurrent engineering is that there are not separate technology and labor concerns. But one part of accomplishing technology policy is making sure that the goals of users are reflected in

technologies developed and deployed. We can improve our *ex ante* review to ensure that technology is used by asking those seeking investment how they are relating to users and how are they investigating their users' needs.

There is a need for customer-driven science and technology investments. The public does not trust investments that are not customer driven. In industry, and in government mission-oriented organizations, this problem is solved by trying to see what the development arm wants from research or, in the case of industry, what the operating department wants from the central research lab. This is done to focus on customer needs. In industry, the ultimate customer is the public—the marketplace. This also relates to what might be termed “design features.” In the area of technology, having firm participation and joint ventures is a way of assuring that the process of selecting investments is more customer driven.

The very fact that some technology investments are high leverage and nonlinear makes them difficult to grasp up front, or even after the fact. But these are exactly the reasons that they may be essential areas for investment. Often the role of research is to create entirely new opportunities, making it less a question of ROI and more an issue of creating a new reality or a new future. This means there is a need to think about how things might be in the future.

The time scales for developing new products are vastly different between the defense and commercial sectors. The government budget process and the time scales associated with it drive product development along time lines longer than those of the commercial marketplace. The government's ability to affect the commercial sector in the near term is, therefore, best accomplished, through collaborative mechanisms such as CRADAs and patent licensing. Part of the strategy must be to bring industry into the development process much earlier because government investments in defense have an impact on the next generation of markets, not today's. Engaging industry as a partner to government affords them a view of the next generation of markets.

Defense firms, in the face of shrinking markets, should endeavor to increase the proportion of R&D they invest in commercial activities to assist in moving toward a greater share of commercial business in their portfolios. It would seem a questionable investment strategy if defense firms directed only a small percentage of their resources toward commercial markets. To that end, one could argue that a 50/50 investment strategy would be appropriate for the long term to realize the goal of a more competitive, affordable defense product. The likelihood of success in being able to bring technologies

profitably to the market is the limiting factor that prevents large defense contractors from more aggressively moving into commercial markets.

Session Two

TAILORING METRICS TO ECONOMIC POLICY OBJECTIVES: THE CASE OF ATP, MEP, AND THE NIST LABORATORIES

The introductory part of this session involved an overview of the three main programs of the National Institute for Standards and Technology (NIST): the Laboratory Program (Labs); the Manufacturing Extension Program (MEP); and the Advanced Technology Program (ATP). The session then moved into a general discussion of how public sector investments in commercially relevant technologies should be evaluated.

THE NATIONAL INSTITUTE FOR STANDARDS AND TECHNOLOGY

Laboratory Program

The traditional, core program at NIST is the laboratory effort. This work was organized and begun as the National Bureau of Standards (NBS) in 1901. In 1988, Congress changed the name of the organization to the National Institute for Standards and Technology to reflect their growing mission.

The NIST laboratory program serves as the nation's measurement laboratory. It provides the technology infrastructure that supports the "business of business." The mission reflects the needs for widely accepted standards which began with interchangeable parts during the Industrial Revolution a century ago. Worldwide, there are many similar institutions, established by other governments and through international agreements to pursue common standards to facilitate trade, production, evaluation, and quality.

The work of the NIST laboratories, today, is very broad. Its constituency includes mature and traditional industries involved in manufacturing, materials, chemicals, and petroleum. More recently, information technologies and electronics have emerged as areas of particular importance. Laboratories also keep-up with emerging new industries such as bio-technology and advanced materials. The mission of the laboratories is to pursue standards and measurement techniques that no one company can do for themselves, but from which every company in an area would benefit.

One area where there is a very strong commitment today, as in the past, is that of metrology—the science and technology of measurement. Metrology has applications in the areas of semiconductors and microelectronics. Recognition of the importance of this work to the microelectronic industry is found in the recent technology road map put together by the Semiconductor Industry Association (SIA). One piece of that road map is a recognition of the role of measurement science and technology in the business of semiconductor manufacturing.

It is apparent that semiconductor technology depends on extremely precise measurements, when one considers the feature sizes of modern semiconductor circuits. Annually, NIST spends approximately \$40 million in its electronics laboratory in the area of measurement and technology infrastructure. Given the pivotal role of semiconductors in the overall structure of the national economy, these laboratory investments are highly leveraged.

Manufacturing Extension Partnerships

The goal of this program is to establish a national network of centers that can reach out and provide access to information and expertise to small manufacturers around the U.S. It is based on a recognition that half of the nation's manufacturing capacity is in firms of 500 or fewer employees. These small firms tend not to be particularly well linked to advances in manufacturing technologies and advances in new kinds of manufacturing business practices. The point of the program is to improve this access.

There are two basic factors to be considered in allocating resources in the MEP program. One has to do with the nature of user needs. When this program began, there was considerable enthusiasm for taking technologies out of the national labs and making them available to the machine shop down the road. It turns out that if you actually go to the machine shop down the road and ask them what they need, the last thing they mention is advanced technologies from the national laboratories. After considerable effort to understand what the customers really needed, the program today focuses on more practical technology applications. The program successfully helps companies to implement just-in-time inventory systems, assists with improving the flow of work on the shop floor, identifies the kinds of training techniques that will help small firms integrate new technologies into their production systems, and so forth. Once in a great while, a technology problem does arise that can be solved by a national laboratory or a university, but this is not the major focus of the program.

The second factor to be considered is this: How do you actually build a national network consisting of 100 centers, each of which is supported on a cost shared basis with a state or local government? That is the top-down picture. The way the network is actually being constructed is by experienced private sector engineers who operate out of the centers and visit the firms in their area. In a very practical, hands-on way these engineers look at the various firms to see how they go about their manufacturing process. They also look at how their business is operating, and help those companies identify technologies to make a difference in their competitive capabilities.

Much progress has been made towards establishing the national system. Today there are forty-four centers in thirty-two states. These are not discrete centers operating on their own. They form part of a network with information shared across state boundaries, with linkages to universities and laboratories around the country, and with organizations such as the EPA, the Department of Labor, and the Small Business Administration.

MEP centers are established on the basis of a competition. Winning proposers are offered an opportunity to have their concept for a center cost shared by the federal government. When proposals come in for extension centers, the factors considered are: "Does this center really understand the manufacturers in its area? Do they understand the manufacturers' needs? Have they coordinated with other service providers in the area so that they are not just proposing a limited, point solution?"

Although there is a goal of national coverage, geography is not considered to be a primary selection criterion. Rather, there is a deliberate strategy to make sure that some access for all manufacturers around the country is established, and this is being accomplished by working with States that have not yet been awarded centers.

The Advanced Technology Program (ATP)

The goal of the ATP is to improve U.S. economic growth and competitiveness through selective, public-sector technology investments that are commercially-relevant. ATP resources are allocated according to strategic technology areas. The canonical model is to invest approximately \$150 million in a technology area over a 5-year period—a limited investment. ATP allocates funding so there is a strong likelihood of a dramatic advance in each of the areas.

Because national economic growth and performance depends on industry, the ATP selects its investment areas from a set provided by industry. A top-down selection

process is neither feasible nor efficient. The best places to allocate funding are identifiable through a bubble up process where ideas come in and are considered against a set of clear criteria. To quote David Barrymore, Deputy Secretary at Commerce: "It is not an epiphany, it is an engineering process." It is not about finding the single best thing in the entire economy to do, it is about finding some excellent things to do.

The process begins with ideas coming in from the technical community, primarily industry, but it is open to the broader technical community. Four criteria are used to evaluate the ideas received:

- *Potential for U.S. economic benefit.* From a systems perspective, if ATP undertakes a technology program, and if it is successful, how will that translate into economic benefit? How will the companies that are involved benefit? How will the technologies that they create help their customers? How will it change the relationship with their suppliers? The issue of whether or not the technologies will ever get implemented is extremely critical.
- *Strength of the technical ideas.* There are many instances where there are marvelous economic opportunities, but the barriers to achieving them do not have to do with technology. In such cases ATP is not the appropriate tool. ATP is looking for places where technical work can start changing opportunity. The program therefore searches for brilliant technical ideas, nonlinear ideas that create a new kind of a reality as a result of their innovation.
- *Strong industry commitment.* Is there enough commitment to complete the program? For example, there are those who will write proposals merely to secure cost sharing. Is a proposer committed to taking the next step in implementing the technologies, and then to taking them out to the marketplace?
- *High leverage opportunities.* How can ATP make a big difference? It is important not to duplicate other efforts. But most important, the program looks for places where small investments result in big returns.

To date ATP has completed two cycles of its industry-interactive process in about a year and a half. This has resulted in approximately 1,000 white papers coming in from industry for comparison with the four criteria.

The white papers are grouped according to technology categories, and are then compared with active programs in other agencies of the federal government. To make sure that duplication of effort is avoided, white papers are reviewed outside of NIST as

well. Where there appears to be significant industry interest and no possibility of duplication of effort, workshops with industry are held to more completely investigate competitive areas.

ATP has made a total of 177 awards. Half of those awards have been won by small companies or joint ventures led by small companies. The process is available and open for small firms.

ROUND TABLE DISCUSSION

The NIST Laboratories

Measurement infratechnologies are one class of infrastructure that NIST provides to industry. These types of measurement-intensive tools and data are found at all of the major stages of the typical technology-based industry. For instance, in the area of R&D materials characterization, data bases are essential now that scientists and engineers are moving atoms around in materials in order to change performance attributes and customize products. You have to be able to measure the results of an experiment in order to convince corporate management that you have achieved an experimental objective. Once you reach the point of commercialization and production, you have very measurement intensive process models that are applied in order to achieve quality objectives to increase yield. Finally, in the market stage, technologically complex products have a number of critical performance attributes. There are often disputes between the buyer and the seller as to how to measure these attributes for purposes of product acceptance.

The typical laboratory inframetrics project at NIST is relatively small. Each project typically supports a large number of applications. The impact of these small investments can be quite significant in the aggregate. To measure the impacts of such laboratory investments, investigators typically sit down with the laboratory technical people and their industry counterparts in order to translate the technical output of the work at NIST into economic impacts. Economics is a foreign language to the typical scientist or engineer, and so it is not a straightforward process. Questions include the area of impact: Is it R&D? Is it production? Is it marketing? Often it is more than one area. The typical NIST project spans 5 to 10 years, so it is possible to collect a reasonable time series of data on the cost to NIST of conducting the research, the cost of

technology transfer, the cost of assimilation by the industrial firms, and the benefit stream that occurs.

Because these projects and costs are bounded in time, the internal rate of return method can be used to measure or estimate the net benefit of a particular investment by NIST. The term "social rate of return" is the economist's version of what the business literature calls the "internal rate of return." Scientists and engineers tend not to like the term "social rate of return," so NIST calls this the "spill-over rate of return." In the Mansfield type of case studies, internal rate of return is used as a metric for measuring the rates of return to a private investment in technology. NIST calls the internal rate of return of the Mansfield type the "innovator rate of return."

From the perspective of national technology infrastructure, one is not concerned with the innovator rate of return because a government laboratory invests in the general public return of the industrial technology. Therefore, what you measure is the spill-over rate.

To date, NIST has looked in detail at eleven laboratory projects. Four have been done in the semiconductor area, so a broader picture is beginning to emerge of how technology-related research at NIST results in spill-over rates of return. NIST is also branching out into related areas such as information technology, looking into areas such as optical fibers.

The output of laboratory research can be a new procedure or a new data base, but much ends up being embodied in standards. For example, in the case of optical fiber, NIST contributed the technical basis for 22 industry standards over the decade of the 1980s. A median rate of return of 167 percent was calculated as the impact of these standards. By comparison, the median rate of return found by Mansfield and subsequent NSF-sponsored studies of private sector innovations was 76 percent. In a more recent Mansfield study, returns to industry from sponsoring academic research were found to be 28 percent. Note that the general rates of return to capital in the U.S. economy are around 13 or 14 percent.

There are some caveats because to this point NIST has chosen eleven projects which, through some screening, have met specific criteria for an evaluation. For example, there was accessible data and sufficient time had passed that there was some reasonable benefit stream to relate to the costs. The feasibility of doing such an impact study varies from one technical area to another, depending on, among other things, the

distribution of benefits across industries. There is a certain amount of selection bias in the projects that NIST has evaluated. It is going to take several more years to accumulate enough individual studies so that we may feel more confident in making generalizations about expected rates of return from this type of infrastructure support. Based on results to date, an economist would say, "Well, you have a negatively sloped marginal efficiency investment curve, so these high returns mean we are way underfunded." That is an argument that our people love to hear and would like to plaster on every wall of Congress.

Preliminary evidence thus indicates that investments in these infrastructure programs are extremely effective. The interactions between industry and NIST, in identifying needs, agreeing upon a program, carrying it out, and then transferring the results are very impressive. In many cases, the output of research is transferred and used before the industry ever gets around to adopting it as a standard. So although standards are important to the economy, certain types of NIST's public sector infrastructure support get used before they become promulgated as a standard.

In summary, the types of quantitative impacts that NIST typically measures include things such as quality, including variability in a particular attribute of a product, and reliability. NIST is also concerned with measuring productivity in terms of yield or overall cost efficiency in the production process within an industry.

Time to market is another impact that NIST frequently measures. Studies try to capture market share impacts as much as possible, but market share is a difficult metric to attribute to the NIST work, even in part.

Studies must account for transaction costs. These include the costs incurred by companies in resolving disputes, for example, sending engineers back and forth to try to agree on how to measure the signal loss rate in an optical fiber or the electrical resistance of a semiconductor chip. These are real costs, just like production costs, that add to the price of the product. They slow down the diffusion of technology into the marketplace. If other countries are better organized and provide their infrastructure more efficiently, it gives them a competitive advantage. Transaction costs are not particularly well known, even to economists, but they are extremely important in terms of the contributions that NIST makes in its infrastructure work.

Qualitative information can be as important as quantitative information in impact studies. Qualitative information complements quantitative estimates and provides a

broader and more complete picture of the contributions that NIST makes. For example, NIST often talks to customers who are one layer down the chain, from the direct beneficiaries. Typically there is no attempt to make quantitative estimates beyond the primary industry, because the farther down that value added chain one goes, the more other factors come into play, and the more difficult it is to isolate the contribution that NIST makes.

The interaction between NIST and industry affects R&D investment decisions. Simply the ability to measure something in a laboratory can lead to new directions in research that were not possible before.

Manufacturing Extension Partnerships (MEP) Program

What is the importance of technology infrastructure if manufacturing is a declining sector in the national economy? A coast-to-coast flight in the United States takes about four hours, during which there are about 2.5 hours of agriculture along one's route. Yet the agricultural sector of the national economy has been a declining one for years. When we try to assign a value to the importance of agriculture to the economy, the problem becomes: How do we count? Do we count farmers, do we count the big animal veterinarians, or do we count the companies that are providing fertilizer so that there aren't so many farmers needed. In fact, we have to look at the agricultural complex.

In the same way, to understand the economics of manufacturing, we have to look at the manufacturing complex. In both cases, it is important to understand the supporting linkages in the economy which allow agriculture and manufacturing to represent smaller and smaller portions of the overall economic picture. When all of manufacturing is accounted for in this way, to include activities upstream from the shop floor, the percentage of the economy that was involved in manufacturing is vastly larger than appears on the surface. Infrastructure is the key to success in maintaining these upstream linkages in the U.S. manufacturing economy. The issue is that the U.S. is less good than other nations at diffusing infrastructure technology. As a consequence, firms tend to move production activities offshore. The question here is: What kind of infrastructure do we need so that we can take full advantage of linkages? The analogy to agriculture is, probably, a pretty good one—we have remained pretty competitive in that field.

MEP wants to emulate the success of agricultural extension. But the program does not want to look like the agriculture one. If manufacturing will represent only 2 percent of the U.S. economy, it will not be desirable to have exactly the same structure in

place when it was 19 percent. If the small manufacturing segment continues to decline, then one wouldn't want manufacturing extension services in every county in the United States. There is a need to size the program to the number of customers. Moreover, if you are funding the same firms and projects after 10 or 20 years, something is not working. A key issue is to make sure that the best activities receive funding. At the moment, MEP legislation has a sunset clause that terminates federal funding at the end of 6 years. This has provoked considerable discussion about what a sunset really implies, and whether the legislation should be changed to continue the program. The real question is how to make sure the program structure remains sufficiently flexible to keep up with changing business environment.

What lessons has the MEP learned from other countries? Other countries have benefited from having a sustained infrastructure program of the MEP kind. Certainly, the European countries, and Japan, Korea, and Taiwan have all benefited from having this type of infrastructure activity. These may provide a model for new kinds of American programs, for example, the Fraunhofer Institutes, which are applications-oriented R&D centers in Germany. There are other possibilities, if we are smart enough and attentive enough to keep these institutions focused on the need.

How does industry view the MEP program? The MEP is considered an extremely valuable program. It is looked upon as being a communications program—how to communicate best current practices among industries. It is interesting to note that MEP is not centered around universities, but instead is centered around the factory floor and guided, to a great degree, by the needs of factory employees. This makes for appropriate assistance for small companies. Big companies can afford to find out what each other is doing. They can afford to go to Japan and find out what is happening. Small companies cannot. We need both big companies and small companies working together in supplier/customer relationships. Therefore, it is in the long term interest of both small companies and big companies that all of U.S. industry gets access to the best current practices. MEP needs to be in place for a long term, even though it will have to change with the nature of industry. Even if we drive industry down to three percent of employment, which should be viewed as a success, then it will still be as important to the nation as agriculture.

Who are the customers of small firms? Large companies who want to become world class or remain world class are investing a lot in their supplier chains. They want their suppliers to have six sigma quality, or just in time delivery, or engage in electronic

commerce. Each of those large companies has some rather specific requirements that they are imposing on smaller firms.

What steps are being taken in the MEP to use information from larger companies to assess the progress of effectiveness of MEP with small companies? MEP is starting to look at supplier chains. It is looking at return on investment to larger companies in the supplier chain. Sometimes, in a price-competitive situation, the benefit, doesn't accrue to the smaller firms but to the larger firms they supply, or to the ultimate consumer.

How does the government know when to get out of the manufacturing extension business? This is an important question since the agricultural extension program has been operating since 1862. The concern is that government initiates such programs and creates a large infrastructure—a legacy of 100 centers—which are supported by constituencies that are very difficult to turn off. As long as the government is prepared to fund such programs, there is no impetus for them to become self-sustaining.

Evaluation of the MEP requires both short and long run metrics. In manufacturing extension, NIST is building an evaluation system to go along with the program. There is an up-front activity of interviewing companies to whom the program has provided services to understand their assessment of what benefits it offers. This also includes a reflection of customer satisfaction.

The second part of the evaluation is to go back and look at companies served to see if their projections were realized. The kinds of successes for companies include things like reduced scrap rate, shorter product cycle times, the ability to see new market opportunities, and productivity enhancements. These are observable within a few years of rendering assistance. They are also fairly concrete outcomes which are projectible, and are measurable after the fact.

Many different types of data come in from MEP centers around the country. Early results reflect the work of 44 centers which served approximately 12,000 firms around the country. Of course this must be compared to the 380,000 small manufacturers operating in the US. The projected benefits to companies from MEP assistance appears to be on the order of an 8-fold benefit for each federal dollar expended. That means for each federal dollar that has been spent on the program, projections from these companies indicate that they will see about eight dollars in economic benefits from business operations. Of course there needs to be a much richer and a much more robust evaluation to verify these claims.

Advanced Technology Program (ATP)

International competition in technology is central to trade promotion and a healthy balance of payments. We are competing in a world market. Industrial competition involves more than firm A or firm B in the United States. We must look at the issue in terms of firms A and B in the U.S., firm C in Japan, firm D in Germany, and so forth. The U.S. is a large country whose internal market has, in the past, allowed us to disregard some of the competitive processes. The countries where competitive processes move most swiftly are small countries like Denmark, where there is no choice whatsoever. Since the mid-19th century the Danes have put in place programs to advance their industries into more sophisticated, high value added niches in world markets.

This has been a wise strategy. For example, at one time Polish hams were starting to sweep into European markets. The Danish response was to ask: "Why would anyone want to buy a Polish ham instead of a high value added Danish ham?" The Danes proved to be right, because the French bought the Polish hams and shipped them to Russia, which is where the Poles had been shipping them in the first place. So in the end the real threat to the Danes was in their heads, it was not Polish hams. The rest of Europe adopted the standards that they were adopting, and the Danes adopted the technology support programs that gave their nation an advantage. The real threat was not hams from Poland but the successful implementation of similar infrastructure programs and similar standards elsewhere in Europe.

Who is leveraging whom? There is considerable talk today about leveraging federal government funds. On the industry side they talk about leveraging their own funds with federal dollars. Collaborative programs are apparently of general benefit. Partnerships imply overlapping objectives so that there is a real mutual benefit. This is described in the business world as a "win-win situation." Government is leveraged because it is working with industry, and industry is leveraged from federal dollars.

Is AT&T, for instance, big enough and rich enough to make such investments on its own? The issue of the size of a company is one that comes up frequently. There has been much discussion about how and where industry is spending its R&D dollars. There is an inside-the-beltway fiction that companies with over 500 employees don't innovate, or don't need federal assistance. Clearly in the case of firms such as Motorola, AT&T, GE, and others, this is patently not the case. However, large companies are decreasingly

spending their R&D funds in areas which are likely to produce socially and economically beneficial spill-overs.

What is the impact on firms not assisted by the ATP from the introduction of new technologies which receive support from the government? When you are developing new technologies you are also displacing older technology. When company A owns the older technology, and company B has the newer technology, and the federal government is supporting B, it is seen as putting A out of business. In the ATP program, this issue was encountered in the field of composites. When the ATP started its composite structures program, it immediately began to hear from the steel industry about how sinful this was because the applications are in things where steel had once been used. An important part of the answer to the steel industry was that, if they wanted to participate in the program they should send in their own technical ideas and show up at the workshop to hear the selection criteria. In fact, no one from the steel industry, or any other industry, indicated that the selection criteria were flawed or incorrect. Either firms see advantage to participating in the program or they steer clear of it. One of ATP's new programs launched in the fall is materials processing for heavy manufacturing. Its participants include steel manufacturers. They did come to the table, and they did play.

How do you capture the potential loss from competitors of firms that are helped? Does this mean that the actual benefit to the economy is considerably less than what is attributable to the immediate beneficiaries when displacement costs are taken into consideration? NIST programs result in companies that are leaner, meaner, more aggressive, have bigger market share, and so on. They do better compared to their foreign competitors. Increasing quality is essential to being a global competitor. If the near term effect is that a company displaces and takes away orders that a less competitive firm elsewhere was getting, this is still good in the long term because it leads to a more competitive manufacturing base—and that is, really, what we are trying to get to. If one is not improving competitive capabilities, one may simply be shifting locations but not improving competitiveness.

ATP uses different time frames for evaluation. ATP very formally segregates the short to intermediate term. None of the metrics during the first 3 to 5 years of a project involve private rate of return calculations, and certainly not social rate of return calculations. Issues addressed during this period include: "Are the performers doing what they said they were going to do in the proposal?" "Are they really doing an

integrated business commercialization planning process while they are doing their technology development?"

Short-term metrics are indicators of success: "Are they really investing new money in the technology themselves?" "Are they attracting industry partners?" "Are there user-customer alliances being formed?" "Is private investor capital being attracted into this technology pool now that would not have been there without the ATP laying the ground work and reducing the risk." "Are jobs being created?" "Are they really thinking through the marketing strategy and what it takes to scale up?"

Longer term metrics incorporate the data gathering built into cooperative agreements, a minimum of every 2 years for 6 years after the project ends. That is still not quite enough, but it is about all that NIST could get. Hopefully, researchers will be able to go back later and capture some more. In the long term NIST will be going back regularly and routinely to do case studies. That data gathering, supplemented by additional broad industry studies by academics can help to ascertain social rates of return, gross or macroeconomics effects on jobs and output, and GDP output.

The complete results from the ATP will not be known in the short run. The short-term operational question is whether or not the program is functioning efficiently. The following information is currently available for preliminary evaluations:

- Assessments of the ATP's own critical operational activities
- Portfolio profiles of applicants, recipients, technologies, and projects
- Evaluation of industry's implementation of both the R&D and business components of ATP projects
- Tracking of short-term and intermediate project results
- Measurement of long-term economic impacts

There is considerable data for the first three items and some data for the fourth. There are only a very small number of projects in ATP that have actually been completed, since this program began with Fiscal 1990 appropriations.

An example of an apparently highly successful ATP investment was that of a small manufacturing company owned and operated by only two individuals. They quite literally had a concept. Nothing had been built or demonstrated. Because of that, they were unable to attract private capital. ATP did a very brief cost-share project with them—18 months. They were then able to demonstrate a laboratory prototype. Based on this prototype they have now licensed their technology and lined up private capital to

continue the development. The firm now employs 35 and has a commercialization pathway to go forward.

The benefits from an ATP project continue long after the project is completed. They continue to flow after the private sector has taken the technology to the marketplace using private dollars, as customers start getting the benefit from the technology. The short term and the intermediate project results include the immediate job growth that has taken place. It is not the full-blown effect, but it is one piece of what is important so far. The fact that firms have strategic alliances and licensing agreements, and the fact that they have been able to attract private capital, are also measures of progress.

Are metrics attainable? What needs to be put in place in order to get at useful measures of effectiveness?

- ATP receives quarterly reports by which it tracks technical progress, and changes in business behavior, how targets change, and how different strategic alliances grow or move. Routinely and quarterly, ATP tracks the global strategies for commercializing the technology in the longer run, as earlier planning is amended.
- Other ATP issues which are tracked include plans for licensing, for manufacture, and for strategic alliance with other companies. What are the opportunities to be pursued with this technology in the long run? Has the firm started investing in production downstream? Has it started doing market analysis? Is it looking at what competitors are doing? Has there been a change in competitive advantage in the marketplace since starting this project?
- Then every year ATP looks at questions like these: Have you attracted financing? Have you, actually, formed strategic alliances? How have they been helpful? Have you started to have spin-off products? Have you started earning license fees? How much have you earned? With the help of academia, the ATP is also developing a longer term model to capture the spill-over effects.

What are the time horizons for assessing program results? In the case of the ATP, it will be many years before the full economic effects can be discussed. In manufacturing extension we are closer to seeing results, but the program is still too young to make any definitive statements. For the NIST laboratories results can be stated based upon over 90 years of experience.

Technology Impact Measurement Issues

There is a need to fight the notion that you can come up with a simple, meaningful, single, quantitative result for something as complex as the technology system. While the political system demands sound bites, there are none that will answer the technology questions adequately. There is a need to fight oversimplification. The issue then becomes: How far back can one provide a family of quantitative answers that, in some fashion, one can discuss results without using vignettes. The answer appears to be that there is a need to convey the order of magnitude effects which result from technology investments, without being able to specify the precise rates of return.

What are good measures? Following are six rules for *ex post* assessments and measurements:

- Measurement must be simple to understand and relate to. A 14th order or a 15th order system that has a lot of inputs that are extremely time intensive to develop, is a system that is too complex. Furthermore, industry is not willing to divulge every detail of their operations, so there must be simplifications which are realistic in this regard. Simplicity also means that measures must have a clear definition that is meaningful to the public. For example, jobs, economic benefits, and the like.
- Measurements must be acceptable to the field of economics. As soon as one proffers a measure the economics profession will place it under a microscope. The result may be assertions that the measure is somehow incomplete, inappropriate, or simply incorrect. Therefore, measures must be defensible in the mainstream fields of economics or economic thought.
- Measurements must be quantitative to the first order. It is better to get a timely answer that is ten to 20 percent accurate rather than an untimely that is one percent accurate. It is better to describe how, based on the \$70 billion that the government spends, that there are answers of the same order of magnitude in terms of outcomes or results.
- Measurements are always "needed yesterday." Getting an answer or set of metrics down the road does little good when trying to respond to issues raised by the Congress within a two, three, or four month time frame.
- Measurement must be able to deal with the panoply of the different types of government investments that go on that make up the fabric of TRP, ATP, MET, and the other government R&D activities.
- Measurement must include considerations of in-kind contributions as well as facilities and resources that are brought to the table or shared by government and industry or within partnerships. This must also include technical

expertise, such as specialized engineering which may be found within organizations and companies.

SBIR is an example of a technology development program with some immediately observable metrics. What are the economic benefits from the SBIR program outside of its direct benefits to government agencies? There are a number of ways to make such measurements. For instance, measures of the amount of private capital investment that results from the government SBIR program.

International benchmarking would be useful for the NIST programs. It may be wise to do some international comparisons for programs. There are comparable programs to each of NIST's major elements in Europe and Asia, and one can follow the experiences there. There are evaluations ongoing in Europe and in Japan which may be of use in justifying programs here. What would be helpful to demonstrate is that one is providing as good a service to industry or to society as our competitors are providing.

The experience of foreign programs may be able to teach us much about U.S. efforts. Foreign programs have not attempted quantitative estimates of the results of their investments. Rather, they get together panels of experts, and make judgments. It is very interesting to see that some of the same problems have arisen in terms of reviews in Japan and in Europe, that the U.S. has had to deal with. As in the U.S., justification for foreign programs has meant recasting them to explain them to various constituencies. This has included putting new names on them, trying to "burn their trails," rather than justification on economic bases. Today there is agreement on the value of more systemic and long term evaluations. There was too great a pressure on them to show short term results.

Session Three
METRICS FOR MULTIPLE POLICY OBJECTIVES:
THE CASE OF TRP AND DUAL-USE

The Technology Reinvestment Project (TRP) is unique in a number of ways. It involves six agencies: the Departments of Defense, Commerce, Energy, and Transportation, NASA, and the NSF. It is intended to pursue commercial/military integration, primarily through leveraging commercial technologies for military purposes. It seeks affordable, dual-use solutions—a dual-use solution being one that is commercially viable and militarily useful.

OVERVIEW OF THE TRP

While there have been a number of different public faces put on the TRP, there has been consistency in the program. The original mission statement was: “To stimulate the transition to a growing, integrated national industrial capability which provides the most advanced affordable military systems and the most competitive commercial products.” The key component of the program was to stimulate the integration of military and commercial research and production activities. This mission statement was put together in December, 1992, and it has survived, until today, internally in the TRP.

In designing the TRP, three different types of goals were originally envisioned. The first was economic impact, and some held that this was the primary objective of the program. The second view, primarily held by the architects of the original legislation, included converting defense industries to either dual-use or commercial capabilities. The third view, which is the one used in constructing the TRP, stemmed from the vision that Bill Perry, John Deustch, and others, had for “commercial-military integration.” This latter view was one which centered primarily on affordability—the idea that the Department of Defense needed to expand its supplier base to include not only traditional defense industries, but also to include commercial or commercially derived products, thus engaging the power of the commercial sector of the U.S. in national security. Dual-use concepts foster a mid-term view of integration; that is, trying to create today the technologies that the military can use when it matures in 3 to 5 years.

TRP does not consider itself as a defense conversion program, although some observers have labeled it as such. It is really a defense transition program attempting to move towards an integrated commercial and military industrial base. Conversion connotes something more akin to what is happening in the USSR—that is, how do you take the capital base and turn it from a military capital base into an industrial capital base with commercial capabilities. That is not what the TRP is doing. There is not enough money to affect such a change on the part of the government. The idea is that, by investing in dual-use, technologies can be made both militarily useful and commercially viable, so that the DoD and the industrial world benefit together.

In addition, the strategy of commercial-military integration envisioned in the TRP is not compatible with the other two views of converting defense industries. Conversion of defense industries to commercial pursuits is an industry decision, not a government decision. If companies want to make a move in that direction and the TRP can help make that move, that is certainly a valid thing to do, but it is not the primary mission of the TRP. Nor is economic impact a primary mission, but rather a by-product of the program and its focus on dual-use.

Areas are selected for funding under the TRP based on military needs. The second part is to raise the needs with industry to sort through their views. A third basis for project selection, which has been criticized, was to recognize that dual-use might include not only military but other government technology needs.

An ad hoc committee representing all of the government partners in the TRP, the six agencies, and now the Services as well, meet to discuss the best way to implement the program. TRP gives those agencies the opportunity to suggest focus areas. As would be expected, many of the suggestions received from the other agencies tend not to have a clear, compelling defense need. There have been controversies because many of those inputs were not accepted because the defense part of the equation was not present.

During the first round of project selection there were 150 need-based topics suggested. The group went through a peer review process to winnow that down to a manageable number—originally 12 were selected. It was the requirement for a strong justification of military need that sorted out the project areas. The TRP then chose its projects through a free and open competition.

The one thing TRP failed to do was have title designations for programs. For example, one that is called the “BART Train” has been severely misrepresented in the

press and on the Hill. In fact, on that project the aerospace contractor has very clear, militarily relevant objectives. Today, the Army spends approximately \$60,000 for precision location equipment on various vehicles. There are two ways to get that cost down. One is to redesign it, using leading edge commercial technology. The second is to have commercial spin-offs that create economies of scale. That is exactly what the program is doing, and one of the test beds that the equipment will be tested on are BART Trains in the Bay area. Unfortunately, the title of the program says "BART Trains." TRP has therefore taken a thrashing by those who want to criticize the program.

TRP is based upon the idea that DoD can benefit by leveraging industrial resources, both in terms of extending its own financial resources, and from rapidly accelerating commercial technologies. It is a 50/50 cost share program, as is the ATP and some other DoD programs.

TRP is attempting to implement what are called "other transactions." The notion is that the current DoD procurement process is a real impediment to government business with the private sector. TRP attempts to overcome this by engaging in agreements which are termed "other transactions." These agreements are very much simplified procurement documents. They, allow companies and the government to enter into agreements that are very similar to those which would be entered into among firms in the private sector.

Metrics to measure the success of the TRP have been an issue which has dogged the program ever since its inception. Congress wrote into legislation in TRP's second year that the program should discuss the number of jobs created, the profitability of firms, and other such macroeconomics indicators, even before the first contracts were let. This has been a real problem. In the TRP program there is a very simple rule for metrics. Good metrics have to relate to a set of original objectives.

Industrial-base impacts for dual-use require very different sorts of metrics, for instance, the extent and success of integration efforts, the improvement of defense affordability, and commercial spill-over benefits. One way of looking at this latter impact measurement might be industrial based broadening and strengthening.

Since development projects are heterogeneous, they must be handled on a case by case basis. In order to do that, TRP is going to be entering into a series of case studies, as well as convening what is being called a "military and commercial evaluation panel." The notion is that peer review is required, both for the investment portfolio as it is proposed, as well as for the status of the ongoing projects.

In order to measure impacts and to tell the TRP story, there is also a need to understand that certain impact measurements are available at certain times. It is not possible to know how many jobs are going to be created early on in a program. It is also not possible to know what the profitability of the firms is going to be—even most industry executives don't really believe company projections out 5 years. Therefore, while in the TRP there is 50/50 cost sharing and companies claim that they will be able to transition a product or process into commercial use and make a profit, it is far from certain what will happen. In fact, that is part of the risk undertaken by government. If there is no risk, there is no need for government support.

There are two kinds of risks in TRP projects. One is the technical risk, which can be reasonably high. The other part is the economic risk. Even if you get a product to market, opportunities may vanish in following years. There is a need to understand that success is not simply getting something to market, but that there are long-term impacts and implications from these technology investments.

What does an economist look for to understand the extent of success of commercial-military integration efforts?

Evidence of co-production. Production of military and commercial items, either on the same production line or in the same facility using shared resources. In the short term one can speak with companies about their planning and their strategies for penetrating both military and commercial markets and try to understand whether they intend to set up separate facilities to produce the items or whether they are going to co-produce them. In the long term the sales of comparable products and processes in commercial and military markets is a metric for integration.

In fact, commercial-military integration embraces a spectrum from commercial off-the-shelf, through military unique products and processes, and everything in between. So we should not expect to see simply commercial items being used by the military. We may have to paint them green, and we may have to change some of the microcircuits, or we may have to install them differently. Nevertheless, with a good understanding of what to look for, one can use data such as sales in both the commercial and military markets, or look at the point of origin, or look at the supplier base, and trace integration back to its source of origin.

Improved defense affordability. It is certainly possible to identify the costs of military and commercial components as they exist in weapons systems. This may be

done in the planning stage. Or one might do this in the production stage. Both are very viable metrics and support the claim that: "We planned to do this." Even if, in the long term there are changes in plans, one at least has a way of pinning down facts and stating, specifically, "This is what I am going to try to do; this is what we think the impact is going to be." Or, "We are producing it this way, and this is what the level of integration is."

Industrial base broadening and strengthening. This has also been termed "preservation of critical defense industrial base capabilities." In this case one would look at whether or not TRP investments led to the continuation of on-shore production of a militarily important item. In some cases this would be associated with the need to retain control of production for items which have particularly long production lead times. One may also look at long term military and commercial contractual relationships as the TRP has attempted to get defense firms and commercial firms to work together and come up with new products and processes that have dual uses.

Industrial base broadening and strengthening through integration also must deal with the different business cultures of defense and commercial firms. These cultural differences are enormous. By having commercial and defense firms work together on TRP projects, we are creating a "human" bridge, a knowledge bridge, an experience bridge between firms in the two sectors. This, of course, leads to technology transfer among the team members.

ROUND TABLE DISCUSSION

Technology Reinvestment Project (TRP)

What are appropriate indicators that a spin-off or spin-on project will have the desired affordability characteristics? The metrics for initiating and monitoring commercial projects in the private sector, and tracking them after the fact, are very well established in industry. The issue here is the idea that military need can spin-off a commercial product that will reduce the cost of the military product. Presumably, if that reduction is going to be substantial, then the commercial marketplace has to become the dominant user. The main objective of TRP is to take advantage of products that are already predominant in the commercial marketplace. The case of semiconductors would be a very good example, as would the case of flat panel displays.

Why are TRP and Title III necessary to insert new technologies into military systems? The TRP and Title III, in some cases, are being used in lieu of technology insertion budgets for the Services. This is because the Services do not have insertion budgets. Nor do they have some of the mechanisms allowed the TRP to move some of these technologies forward through the use of other agreements.

One of the purposes of a TRP metric would be to identify how broadly a dual-use approach could spread inside of military operations. There is both the question of spin-off, which may be easier, and spin-on, where many other factors must be considered, including military suitability. Under what circumstances does this work, and what are the obstacles to doing it? Many civilian technologies are, by some measures of performance, way ahead of the military. We also know that the military's needs are quite different so that it is not so easy to go from highly sophisticated civilian components directly into military applications. Commercial firms would go through a series of steps and not make a large jump.

Obviously today the only metrics you have for TRP are performance of the TRP project because they are at most 2 years old. Most TRP projects have an average age of a year or a year and a half. So the only metrics you have today to look at are: "How are those programs performing against goals that were established?" That includes—and, this is what is a little different about TRP or dual-use—an assessment of the commitments made to commercialization.

Where is the team or company involved on the path to sorting out commercial markets? That is not simply a quantitative assessment. In addition you have the fairly standard cost schedule performance metric.

Also, you have a metric with respect to who the players are. If one reviews the Service R&D programs, how many of them involve defense firms, and how many involve both commercial and defense firms (dual-use) you will find some major differences when compared with the TRP.

The long term for TRP projects is 3 to 5 years. At that point one can begin to use conventional commercial metrics that are well known and well established. One can also use conventional military metrics for judging the impact of specific TRP projects. Those are fairly well known.

Actions which enable integration can also be measured, for example the reduction of military standards and military specifications. It is possible to measure the degree to

which contracts have changed, solicitations have changed, and the degree to which military specifications are listed in documents.

A crossover point for short term versus long term metrics for dual-use technology would be achievement of joint production which should lead to economies of scale and also economies of scope because there are different performance requirements for defense versus the civilian market.

In defense we measure products in three ways: cost, schedule, and performance. We should be able to take each of those three measures and ask the impact of the TRP program: What was the cost reduction per unit? Did we get it sooner than we otherwise would have gotten it? Do we consider that worthwhile?" These, along with performance measures, tend to be qualitative judgments.

If TRP had not funded EPLARS, would the Army still have funded it? The Army funded EPLARS well before TRP was ever formed. They abandoned it because it was too expensive. TRP picked it up to make it less expensive. The Army has now stated that they will purchase EPLARS if the TRP meets its cost reduction goals.

What is industry's view of the TRP. With all of the controversy over the TRP program, there is certainly a divergence of opinion. The TRP program allows companies to do some things that they, perhaps, would not have otherwise done. TRP makes the decision to undertake some company investments much easier, although it is impossible to say whether these investments would have been undertaken anyway. Most examples of successful TRP projects are highly militarily oriented and may have industrial spin-offs. For a defense contractor, it is much easier to justify investments in projects which have a defense relevance and the potential for a commercial spin-off, than for a commercial contractor where commercial markets are the primary target.

For instance, in medical imaging systems Loral had a program prior to the TRP. But the TRP program allowed Loral to take a basic imaging system, where one takes all images from hospitals, whether they be X-rays, CAT-scans, or nuclear scans, and put them in digital form. This allowed Loral to leap-frog by taking the technology and applying it to a telemedicine. For the military, the technology supports the extension of highly trained medical expertise to the hinterlands or the battlefield.

Loral also has a TRP program in uncooled electro-optical technologies. The end goal of this project is to bring the cost of infrared focal planes down considerably by getting rid of the cooling apparatus, which is one of the big cost drivers in the system today.

Loral had an agreement with Honeywell at the time it bought its IR imaging system division to tap into that technology, but there was a big cost of technology transfer; and there was a need to make some changes to the technical process. Again, the TRP program made it easier for Loral to do this. The project is now well underway and would appear to be extremely successful with a tremendous potential for the commercial world.

TRW has a program in precision laser machining derived from its development of solid state lasers, primarily on behalf of the military. TRP gave TRW the opportunity to do initial development work to demonstrate commercial applicability. It has been an excellent program, and it has benefit on both the military side and the commercial side. TRW, being a company with both sides of that business within the corporation, has also been helped by TRP moneys to bridge the corporate cultural chasm. In pursuing its TRP project, TRW has attempted to quantify the share of the marketplace it expects to gain, how attractive this is going to be in terms of returns, and so forth. There is the constant need to update and revise such assessments, because the world changes, but they serve as a guide for understanding what may happen in the future.

In terms of global competitiveness, in the laser machine tool market, TRW is quite concerned about losing market share to the Japanese and Europeans. Unless TRW brings products like this onto the market, it will lose global share. TRW has also assessed the benefits of laser machining for the environment—a social benefit which derives from the reduction in automobile weight which becomes possible, and the gasoline savings which therefore results.

Is the controversy over the TRP a “red herring?” There is, obviously, a huge controversy over the Technology Reinvestment Project, politically. There are questions as to whether it is a proper use of government funds. There are questions as to whether it is the right size. There are the questions as to whether it is the proper use of DoD money.

All of these are red herrings and miss the fundamental point, which is that dual-use is absolutely essential to the Department of Defense, that commercial/military integration is essential. Therefore, the question here is how do you measure the success or failure of this particular program? Is it a stalking horse for how you decide means and metrics for the broader task?

On the defense side, since the primary goal is affordability, there is the metric of cost reduction against a base, which offers some intermediate-term measures. This would also be reflected in how much DoD is in fact modifying its own processes, specifications,

and standards. On the commercial side, it turns out that there is already a well developed methodology for determining the effectiveness of a development program, including measures of market share, cost, adhering to milestones, and so on.

If we sat down and designed the tests for the TRP, or designed the tests for dual-use, we would be able to measure what has occurred, what has not occurred, and what will take time to occur. When we are talking about technology we are talking about development. Even more importantly, we are talking about cultural changes that take years, even decades. That is why it is important to have intermediate and long term measures.

Dual-Use Investments

The case of Flat Panel Displays. Congress mandated that DoD spend a certain amount of money on AMLCD, Active Matrix Liquid Crystal Display, which is a little more narrow than the program's original intent. The original notion of Congress was to create purchase commitments or incentives to help a particular vendor with their business. One of the things done as part of the National Flat Panel Display Initiative was to use Title III dollars to stimulate demand by the insertion of the panels into weapon systems.

The Flat Panel Display Initiative, in turn, wanted to find out what was needed to help the military in gaining access to the use of flat panel displays. This involved canvassing the management offices of programs that were using displays or thinking of using displays, particularly those using CRTs, to find out what they could use in the way of incentives in terms of qualification or early purchase of displays. For the \$20 million thus far spent in this program, there are over \$200 million worth of displays going into systems that would have used CRTs. The offices either did not have a separate account to fund new equipment qualification, or they had insufficient funds to purchase the flat panels early in the production phase (to help vendors and helps lower production costs).

There is the question of trying to get the commercial into defense versus getting defense into commercial. One might argue that the objective for the Department of Defense is to get lower cost and higher performance weapons systems, and that commercial-military integration has been concluded to be a means to do this. Therefore, what one needs is to have some measures of means and also some measures of objective in the sense that the end result is lower cost weapon systems.

In terms of being able to measure whether we have the same product built according to military and commercial specifications with the same performance, this is difficult because the military almost never builds a military and a commercial variant of a weapon system. There is very good empirical data that shows that, as weapon system performance keeps going up, the cost keeps going up with it in the defense world. In the commercial world as performance goes up, the costs keep coming down. So there is, probably, something that says that we are not violating a law of nature by continuing to drive costs down.

The Services probably would not have embraced the concept of commercial-military integration on their own without some other pressure. The outside pressure is the pressure on Service budgets. The reality is that the force structure is going to be smaller. You have to maintain a qualitatively superior force at the same time you have to buy sufficient numbers of weapon systems. The numbers do not work out unless you can leverage the commercial sector to the maximum extent. As for commercial specifications, it does not matter if your PC takes five minutes to initiate, but if one has an incoming missile, this becomes important. So time to an officer in the military is a lot different than time to an economist.

The prime reason that the commercial product is lower in cost is volume, volume, and volume. That says that you are going to have to look for a place where the commercial use will outweigh in numbers the military use by a factor of 100 or a 1,000. Can you find a product where the commercial use is 100,000 times the military? If you can do that you can guarantee a cost reduction.

If you are going to use the commercial industrial base, then the products must also be successful in the world marketplace, and they have to be managed by industry and not by the military. That is a very tough decision DoD must face up to because, once you start imposing military requirements and timing on the commercial product, you will kill the commercial product.

Defense has its unique industrial base that has been very content to provide unique systems in the past, because every time you build a new submarine, you build a whole new combat system, and it was a nice couple of million dollars in somebody's pocket.

What is the time horizon for applying dual-use metrics? One way of addressing the time question is to look at the product's life cycle. It may shock people from the

commercial world, but the average defense weapons system now takes 16 to 18 years and is stretching towards 20 years from initial concept to first production. One of the motives of commercial-military integration is so the defense can be first to market with the next generation military weapons systems. To get within commercial time horizons requires a dramatic change in the whole acquisition and development cycle. A reasonable time might be about 5 to 7 years. But the point is that you are not talking months, and you are, probably, not talking even a few years if you are going to look at the ultimate effectiveness of the change. You can't afford to wait that long on individual projects.

Technical and cost metrics are relevant to military missions. You can come up with a number of technical metrics, you can come up with some cost metrics, but the only way they make sense is to put them in the context of the systems that the military is able to procure. You take the performance measures of the systems. You can quantify those. We do that all the time, just to justify them. But you have to put that in the context where DoD is spending 40 or 50 percent less, and it is buying systems that are performing at the same level.

Order of magnitude estimates are good enough. It is important that one has some quick assessment of goodness that one can get to—perhaps 80 percent good answers with 20 percent of the effort. Nit-picking estimates is counter productive and ignores the order of magnitude benefits which can result from the pursuit of projects. That is: “It is good enough to say that you are going to create 7500 jobs. Maybe it is 6,000. Why should we care as long as the magnitude is correct?”

Appendix A

ROUND TABLE ANNOUNCEMENT

ASSESSING THE ECONOMIC AND NATIONAL SECURITY BENEFITS FROM PUBLICLY FUNDED TECHNOLOGY INVESTMENTS: AN IDA ROUND TABLE

On April 27, 1995, you are invited to a round table discussion on the economic and national security dimensions of public sector technology investments hosted by the Institute for Defense Analyses (IDA), and jointly sponsored with the White House Council of Economic Advisors (CEA) and the White House Office of Science and Technology Policy (OSTP). The purpose of the round table will be to explore practical issues associated with the selection of technology investments by various government agencies, and how to assess or measure their success. Our co-chairs will be Joseph Stiglitz, Member of the CEA, John Gibbons, Director of OSTP, and Christopher Jehn, Director of the Strategy, Forces, and Resources Division, IDA. A listing of the distinguished invitees from the academic, business, and government communities may be found below.

Background

Investments in applied technologies are an important part of the current Administration's efforts to foster long-term economic growth and national security. Policies include explicit links between federal government technology programs and the goals and priorities of U.S. industry. In this era of highly constrained budgets the use of technology funding to further economic and security goals involves the following key issues:

- How should agencies with applied technology programs select where to invest public resources?
- How should we measure the results of our investments in technology development and application?
- What lessons have we learned about managing the intersection of economic growth, national security, and the pursuit of other national objectives?

The transition in federal science and technology (S&T) policy occurs against the backdrop created by the end of the Cold War and the simultaneous intensification of global economic competition. During the previous half-century, the United States approached S&T investments within a framework most notably described by Vannevar Bush—government supported basic science and procured the first technological fruits of space- and military-related research as products for NASA and the Department of Defense. Through the mid-1970s, commercial spillovers from federally-funded R&D and procurement helped the United States to maintain a clear leadership position on all fronts—political, scientific, military, and economic. The United States used its position to promote open trade and global economic development to the benefit of both its allies and itself. In the process, it also assisted in the creation of

sophisticated economic competitors, the most successful of whom, many believe, used government policy more purposefully than the U.S. did to leverage science and technology for the advancement of national welfare.

For policy makers in the United States, the objective of linking the complementary *technology* activities of government and industry has become increasingly important as a result of foreign competition. At the same time, the end of the Cold War has profoundly altered the political landscape and changed the basis for government technology investments. Commercial spillovers from military research have diminished, and today dual-use and spin-on technologies appear to offer the greatest promise for meeting the goals of national security while also stimulating economic growth.

Current administration technology policy emphasizes the central importance of technology investment in building economic strength and spurring growth. This new policy includes a key role for government-industry partnerships in strengthening America's industrial competitiveness. The Administration also recognizes the need to select these programs carefully to ensure that they are efficient and offer measurable results.

The strategy of cost-shared government-industry investments in high-risk technologies for commercial application, and dual-use technologies for application by both military and commercial industry, constitutes a new direction in U.S. security and technology policy. Clearly there must be an accounting for the tangible benefits the public receives from these taxpayer investments and the results should be monitored and effectively measured.

The Round Table on Assessing the Economic and National Security Benefits from Publicly-Funded Technology Investments will review and seek to improve the Administration's ongoing efforts to create a consistent assessment framework for measuring the results of its technology investments. Invitees include many of the foremost students of the economics of technological innovation from academia, industry, and the federal government. We hope to explore the current "state of understanding"—the applicability and meaning of different types of quantitative and qualitative measures to different types of government technology investments, and the linkages we can identify between research, innovation, and long-term economic growth.

The Round Table is organized around three Topic Areas. We have asked several invitees to offer their observations on each topic to begin each discussion, and assigned facilitators to keep the group focused.

Topic Area Sessions

I. **Decision Criteria for Technology Investments: Understanding the Rationales for Commercial and Dual-Use Technology Programs**

The Round Table will begin with a session on *identifying indicators which may be used to help government decision makers target their publicly-financed investments on areas likely to generate high social rates of return.* Questions to be addressed include: What are the criteria for choosing public technology investments? How can we identify investments with a high probability of spillovers? What can we learn from the experience of other nations, states, and private

industry about identifying areas for investment with a potential for high social returns? And, finally, how can performance measures be used, along with sunset provisions and other limits on investment, to tell government decision makers when to "pull the plug" on public investments?

learned from dual-use that will benefit public technology investments for other national objectives such as health, energy, the environment, and education?

II. State of Understanding and Measuring Results

What do we know, and when do we know it? What sorts of impacts are we trying to measure? Are these the right ones? The emphasis of this session will be to identify *the strengths and weaknesses of the available tools for assessing public technology investments, and how to apply different sets of performance metrics to different types of technology projects?* Questions addressed will include: What are the uses and limitations of the quantitative and qualitative measures we currently employ? When are quantitative measures inappropriate and misleading, and how can qualitative approaches be made more rigorous and broadly applicable? Given that the outcomes are only apparent in the long term, what sorts of short term and interim measures are appropriate?

III. Dual-Use: Understanding The Intersection of Military and Commercial Benefits

What is dual-use? What is its role in promoting a more robust national security? *How can national security benefit from dual-use technology investments and an integrated commercial and military industrial base?* How could such integration lead to more affordable weapons systems? What do we know about managing the intersection of defense needs, commercial environments, and economic growth? Are there lessons to be

Appendix B

READ-AHEAD MATERIALS

**Assessing the Economic and National
Security Benefits from Publicly-Funded
Technology Investments:
An IDA Round Table**

Read-Ahead Materials

April 27, 1995

**Institute for Defense Analyses
1801 N. Beauregard Street
Alexandria, Virginia 22311-1772**

Session 1

SESSION ONE: CRITERIA FOR SELECTING AND EVALUATING PUBLIC SECTOR TECHNOLOGY INVESTMENTS

In general, public investments in technology development and diffusion in the United States have been aimed at achieving specific policy objectives, such as those associated with national defense, environmental protection, and improved health. Since the late 1970s, however, a growing number of public technology investments have also been made with an eye towards improving industrial or economic performance. Unlike their predecessors, these more recent investments have incorporated economic considerations as part of their *primary* objectives, indicating a clear transition from a neutral to a positive interest in economic benefits on the part of public decision makers. As a result, decision makers must now consider the following key questions: On what scale should economic benefits be measured, and what are the most appropriate methods for making such decisions when future outcomes are highly uncertain?

The overriding economic rationale for public sector technology investments is that they may be used to promote market efficiency when an innovation is seen as easily "appropriable." By appropriable we mean a circumstance which arises when firms believe that they will be unable to capture a sufficient stream of monetary benefits from a technology investment to compel them to commit resources to pursue a given innovation. As a result, potentially important spillovers, or "positive externalities," in the form of benefits that would become available to other firms (or to consumers) will not materialize. In such cases an economist would state that the *social rate of return* to a technology investment is higher than the *private rate of return*. In general it is recognized that when this is true the private marketplace does not lead to an optimum social outcome since firms will tend to underinvest. As a result government is believed to have an important complementary role to play either by sponsoring research itself or by subsidizing private-sector research.

Accepting the above rationale for public sector technology investments, however, does not relieve government decisions makers of the burden of choosing among different investments and accounting for their ultimate effects. Even though, in principle, economic analysis can capture both the direct economic returns and the "extra" economic

benefits that spill over to other parts of the economy from a publicly supported investment in new or improved technology, the specific contributions of the government effort are exceptionally difficult to quantify.

As stewards of the public's trust, government decision makers are therefore confronted with two related measurement tasks, one involving the means appropriate for choosing among proposed technology investments, and the other involving the methods for measuring their ultimate results. In the former case, the most widely used approach by government for choosing technology investments involves so-called peer review. In the latter case, both individual project case studies and statistical (econometric) analyses have been employed.

Choosing Investments Before the Fact: Peer Review

Most government investments, whether they are in new technologies or direct procurements, are compelled by statute to undergo a competitive process designed to reveal the strengths and weaknesses of proposed alternatives. In the case of procurements, when the item to be purchased is known or specified, financial costs are key to making decisions. In the case of technology investments, however, usually the competition takes place across heterogeneous approaches to solving a problem or advancing the frontiers of scientific knowledge and technological know-how. Also in the case of technology investments there is generally extreme uncertainty and therefore no means of accurately making financial or economic forecasts. As a result, a paucity of quantitative metrics exists and qualitative approaches are in widespread use.

Typically, for the purpose of choosing among technology investments government decision makers have turned to some form of peer review where subject matter experts are employed to advise the government project managers on the selection of investments. Of course this approach is not without its own set of problems. For instance, such reviews inevitably rely a great deal on the reputation and experience of the reviewers, and the results are often skewed by the "fraternity" effect, wherein peers who focus on very narrow areas of technology overestimate potential social returns. Conversely, peers who have built a reputation as experts in particular technical areas may also find themselves overestimating the risk of funding a viable but unorthodox approach, or perhaps they may be unwilling to fund new, unknown investigators.

Despite these weaknesses, peer review will remain central to the ex ante choice of technology investments by the public sector. We ask, should more diverse sets of

reviewers be used, including experts from a variety of science and engineering disciplines and a variety of public and private-sector backgrounds? Might it be beneficial to institute a system of checks and balances to “review the reviews?” If economic returns are central to the rationale behind technology investments, then should social scientists be added to review panels?

Evaluation After the Fact: Case Studies

Policy analysts often use case studies and historical examples to assess—ex post—the social returns from public investments in technology. For instance, at the microeconomic level much has been learned from controlled, structured comparisons between the development of similar technologies in different national contexts. Such evidence is used to discern whether distinct technology trajectories or “national innovation systems” exist. Some researchers go so far as to infer that specific results are suggestive about both the possibilities and limitations of government-industry partnerships. However, it is important to not read too much into such anecdotal evidence.

In virtually every instance, technology developments singled out for analysis have been selected because they evidence particularly marked economic impacts, positive or negative. Thus a study confined to cases where public technology investments appeared to produce high social returns—jet engines, computer-controlled machine tools, the Internet—would tend to reach conclusions diametrically opposed to those of studies that emphasized public technology investments that obviously failed—synthetic fuels, the supersonic transport, the fast breeder reactor. Absent carefully controlled comparisons of a sufficient number of both ordinary and extraordinary cases, such studies do not appear to tell us much about the likely outcomes from new technology investments, public or private.

Evaluation After the Fact: Statistical and Econometric Analysis

Attempts to quantify the economic impacts of public technology investments through statistical (econometric) analyses generally begin with a model that attempts to specify the relationship between the technological inputs (e.g., dollar values for R&D spending on technology development or diffusion) and the economic outputs (e.g., some measure of technological innovation—for example, growth of output or productivity). Attempts have also been made to measure what is known as “diffusion,” for example the number of numerically controlled machine tools adopted or the number of production workers trained to program them. Such analyses typically proceed in two steps. First,

direct and indirect rates of return on public investments are calculated. Second, an attempt is made to determine whether the public investments have promoted more spillover benefits than the market would have generated on its own, or whether public monies simply displaced valuable private investment.

Econometric methods tend to work best for measuring the impact of privately funded R&D because the inputs and the outputs of R&D can be more precisely identified for a single firm or industry. In contrast, measuring the economic value of a public investment in technology requires a method for addressing the indirect effects of the public investment on a wide range of firms and industries. This requirement presents conceptual and methodological problems that may limit the conclusions that can be drawn. Industrywide or economywide studies capture spillovers to technology investments more effectively than studies of particular firms or sectors, but this presents analysts with a choice between two less than perfect options: narrow the investigation and thus miss some of the spillovers, or aggregate many sectors but muddy the results. Either alternative limits the usefulness of the analysis.

Measurement Issues in Evaluation

How should we estimate the contribution from public sector technology investments due to a particular program? One way is through a process of elimination. For instance, many investigators begin by modeling the quantitative contributions of such inputs as capital, labor, raw materials, and worker skills to outputs, usually revenue streams attributable to an innovation. Ironically, technological innovation in such studies shows up as an “unexplained” residual—it appears as the unexplained quantitative gain to output. To derive the net impact from public sector investments this residual is then compared with the size of the initial technology investment. The real complexity in performing such calculations lies not in making the calculations, but in obtaining believable data.

It is notoriously difficult, for instance, to assign quantitative values to qualitative improvements brought about by a new technology—especially when the technology appears in the form of an entirely new product line or a brand new industry created over a period of years. It also turns out that the benefits accruing to producers in the form of profits are easier to measure than the benefits that accrue to consumers in the form of lower prices or the ability to do new things. These benefits can only be estimated using

the concept of “consumer’s surplus,” that is, deriving a measure of the premium that consumers would have been willing to pay, on average, for the new product.

Because of the problems associated with tracing quantitative impacts from technological changes, studies of the return on investment in technology tend to show higher impacts for investments resulting in process innovations (i.e., making existing products more efficiently) than for those that result in product innovations (i.e., creating new types of products or new versions of existing ones). Perhaps more important, studies of incremental improvements in technologies also appear to offer more believable and tractable estimates of the economic impacts from technological changes than do studies of the effects of far-reaching, radical innovations, such as integrated circuits. The problem in estimating the impacts of such truly revolutionary technologies is that they tend to generate structural transformations in the economy and give rise to entirely new product families.¹

Hard as it is to estimate precisely the output of a public technology investment, such measurements may be relatively straightforward compared with the measurement of the investment itself—the “input.” In other words, how does the analyst characterize the activity of a particular program or public-private partnership? Statistical models typically measure only the amount of money spent on the government-organized R&D effort and thus exclude quantification of subsequent downstream activities—essential inputs to technological innovation—such as “learning by doing” in production and “learning by using” in consumption. In addition, value attributed to a public investment in technology development or diffusion must take into account both the time horizon for which the benefit is being calculated and the objective for which the project is being undertaken, e.g., fundamental research, technology development for public missions, pre-commercial technology development, and industrial modernization or diffusion.

Issues for Discussion

- In the areas of peer review and evaluation (quantitative and qualitative), which limitations are fundamental, and which can be overcome with continued effort?

¹ Public investments in technology that contribute more to product, as opposed to process innovation, and to radical innovation, as opposed to more incremental progress, may in fact be undervalued by econometric analyses. Such analyses measure average rates of return, not marginal rates of return. Since we expect average returns to exceed marginal returns, we know that quantitative studies are apt to overstate shifts at the margin, which is precisely where public technology investments have their effects.

- What can we learn from the experiences of companies and academic researchers in the use of these methods?
- What can be learned from past attempts at publicly supported technology development in the United States and contemporary efforts in other countries?



Session 2

SETTING PRIORITIES AND MEASURING RESULTS

Growing appreciation of technology's pivotal economic role is leading to changes in federal R&D investment strategies. The Clinton Administration aims to accelerate technology development and application as part of a national effort to foster long-term economic growth that creates new high-quality jobs, builds new industries, and improves the U.S. standard of living. With strong support in Congress and industry, the Administration advocates direct, purposeful investment in commercially relevant technologies. Moreover, the new policy assigns the federal government to the role of partner to industry—as well as to labor and academia—in working to catalyze and facilitate technology development, application, and adoption. An operational aim is to focus and leverage federal expenditures so that relatively small investments yield meaningful economic benefits for the nation.

Like the post-World War II decisions that successfully aligned federal R&D spending with defense and other national needs, today's policy decisions are reckoning with new circumstances wrought by the end of the Cold War, intensifying global economic competition, the rapid diffusion of discoveries and innovations across international borders, and the increasing technological intensity of modern manufacturing and service industries.

This transition in federal technology policy is occurring during a period of constrained federal budgets, prompting two frequently asked questions: First, how do agencies with technology programs identify and select areas warranting investment of federal resources? Second, how do agencies measure the results of their technology investments and ascertain whether these investments are yielding their anticipated national benefits?

The Mission and Role of NIST

These questions are especially relevant to the National Institute of Standards and Technology, part of the Commerce Department's Technology Administration. The Clinton Administration has assigned NIST to an important role in its plans to help U.S. industry to improve its development, commercialization, and adoption of new technology.

NIST's explicit mission is to promote U.S. economic growth by working with industry to develop and apply technology, measurements, and standards. [See box on next page, NIST in the Context of Federal R&D.]

An operational aim is to focus and leverage federal expenditures so that relatively small investments yield meaningful economic benefits for the nation.

The agency's portfolio of programs features four approaches to carrying out its mission and serving U.S. industry.

Under this mission, unique among federal agencies, NIST's direct customer is U.S. industry, which, in turn, is the means to accomplishing the agency's ultimate objective of fostering sustained economic growth that benefits U.S. citizens. The agency's portfolio of programs features four approaches to carrying out its mission and serving U.S. industry:

- ◆ an Advanced Technology Program (ATP) that invests in cost-shared projects in companies to develop enabling, high-payoff technologies that otherwise would not be pursued because of technical risks and other obstacles that discourage private investment;
- ◆ laboratory research programs focused on meeting U.S. industry's infrastructural technology needs, including standards, measurements and measurement technologies, evaluated data, manufacturing process models, product-performance tests, and quality-assurance techniques;
- ◆ a Manufacturing Extension Partnership (MEP) that is scaling up to a cost-shared, integrated, nationwide network of over 100 manufacturing extension centers to help small and medium-sized manufacturers to modernize their production capabilities; and
- ◆ the Malcolm Baldrige National Quality Award program that provides criteria for assessing quality management and competitiveness and sharing information on successful strategies.

NIST in the Context of Federal R&D

The Clinton Administration has begun to make a clear transition in technology policy. It is moving the government from the four-decade-old R&D policy based on post-World War II priorities to a policy that specifically includes an investment strategy designed to strengthen America's industrial competitiveness. NIST's programs are one important part of this transition.

The federal government is responding to global economic changes by:

- ◆ Direct investment in civilian technology for economic growth. NIST is the part of the federal R&D investment that focuses explicitly on this mission.
- ◆ Increased emphasis on directing defense R&D toward a dual-use technology base. The Defense Department's Advanced Research Projects Agency has led technology efforts to foster the growth of an integrated industrial base that is economically competitive and able to meet military needs. This approach is now expanding to other parts of the defense investment.

NIST aims to be a strong partner to U.S. industry. Over nine decades of working with U.S. companies, its laboratories have developed a culture of cooperation. Indeed, a recent report by the Council on Competitiveness described the NIST laboratories' process of working cooperatively with industry as "the most streamlined of all and is perhaps the best model for other federal labs to follow. ... NIST is very flexible and able to respond quickly to industry's inquiries without bureaucratic interference."¹ This traditional culture is the base upon which NIST will build to meet its new challenges.

Need-Focused Priorities, Results-Driven Measures

NIST programs are guided by measurement and evaluation systems that the agency uses as it sets priorities, evaluates operational performance, and assesses near- and long-term returns on agency investments and activities. Priorities are set and results are measured on the basis of benefits realized by U.S. industry.

Conferences and workshops regularly convened by NIST are among a variety of tools that the agency uses to identify industry's high-priority technology needs. Industry input helps to set the direction and emphasis of NIST programs, and it encourages industries and individual companies to shape and participate in new initiatives. One result of this process is high levels of industrial participation in NIST programs; another is solid agreement on technical objectives.

- ◆ **Increased industry access to commercially useful technology developed in government laboratories for other purposes.** The Department of Energy and the National Aeronautics and Space Administration, for example, are working to leverage their laboratory investments for economic benefit.
- ◆ **Maintaining a strong commitment to basic science.** A healthy and productive national science base—the world's best—will continue to be a critical source for future technological progress. The National Science Foundation and the National Institutes of Health are key players in this endeavor.

In the context of these new directions in federal technology policy, NIST has an important, tightly focused role to play. As the NIST budget grows, the agency's share of funding will increase but will still remain a small fraction of overall R&D spending: less than two percent of the federal allocation and less than one percent of the nation's total R&D expenditures. Working in partnership with industry and coordinating closely with other federal technology agencies, NIST can contribute significantly to the national effort to accelerate the benefits of technology for economic growth.

"NIST is very flexible and able to respond quickly to industry's inquiries without bureaucratic interference."

NIST seeks and relies on industry input on the direction and content of its program at several levels of organization. For example, the Visiting Committee on Advanced Technology, a nine-member advisory body that traces its origins to the founding of the agency in 1901 and is composed largely of industry representatives, meets quarterly to review the policies, budget, organization, and programs of the Institute. Indicative of the committee's oversight are a 1992 evaluation of NIST's strategic planning process, subsequent reviews of the strategic plans of several laboratories, and a 1993 study of the strategic direction of the Advanced Technology Program. In addition, each of NIST's eight intramural laboratories undergoes annual performance assessments by independent panels of experts from industry and academia, convened by the National Research Council.

Continuous Improvement

Like any organization aspiring to world-class status, NIST must critically evaluate itself and scrutinize its programs through the eyes of its customers. Likewise, systems and mechanisms for setting priorities, evaluating performance, and measuring impacts must be continually strengthened and improved, paving the way for improvements in the quality and content of programs and services.

Scaling Up, Managing Growth

President Clinton's economic plan calls for increasing NIST's total budget from \$384 million in FY 1993 to \$1.4 billion in FY 1997. While the total NIST investment will still be a small fraction of the federal R&D budget, the growth represents a significant challenge for NIST to scale up rapidly while maintaining the quality of its activities. The agency is meeting the challenge through carefully developed management plans. The strategy is to build on NIST's proven approaches for working with industry and to achieve scale-up with minimum staff growth and bureaucratic overhead.

Two programs will account for more than half of the expected increase in the agency's budget through 1997. The ATP will grow from \$68 million in FY 1993 to \$750 million in FY 1997. The MEP will increase from seven manufacturing technology centers to a nationwide network of over 100 extension centers. Both programs have been pilot tested, and results attest to their potential to produce important macro- and microeconomic benefits. From their inception, the ATP and MEP have been designed to be national in scope. And, because the funds in each program are for activities performed in the private sector, neither will require large increases in NIST personnel. For FY 1997, each program will operate with a total staff of under 100 staff members.

The strategy is to build on NIST's proven approaches for working with industry and to achieve scale-up with minimum staff growth and bureaucratic overhead.

The focus on methods for setting priorities, evaluating operational performance, and measuring results is especially critical now, as the Administration proceeds with plans to nearly quadruple the NIST budget by 1997 and as public expectations for economic returns on the agency's technology programs increase commensurately. [See box on Scaling Up, Managing Growth.] The ATP and MEP will scale up rapidly, growing from pilot projects to programs of the size necessary to achieve national economic impact.

Each NIST program aims to accomplish objectives that depend significantly on industry's behavior, capabilities, and commitment. Measurements of performance and impact are critical, the basis for improving the effectiveness and extending the reach of NIST programs. Yet, there is little precedent in the federal government—and inconsistent results in industry—when it comes to measuring the results of technology investments.

Returns on R&D investments typically do not begin to accrue until several years after research is completed. This lag between expenditures and returns—and diffusion of expected benefits across broad sectors of the economy—makes assessments of the economic impact of most ATP projects and much of NIST's laboratory-based R&D a long-term endeavor. Because economic effects can be projected but never known with certainty in advance, NIST must select priorities

Direct funding of NIST laboratories will roughly double between FY 1993 and FY 1997, to about \$400 million. This increase will address a shortfall in national capability that is the result of two trends. First, during the past several decades, NIST's laboratory budget has been flat or eroding while new industries—such as biotechnology and computer networking—have emerged and the technological complexity of established industries has increased. The result has been a widening gap in our national measurement infrastructure. Second, NIST laboratories have been heavily dependent on funding from other government agencies: for example, about 25 percent of the NIST laboratory staff was supported by Department of Defense funding in FY 1993. As direct appropriations for NIST laboratories increase, the agency will be better able to respond to industry needs for infrastructural technologies. The laboratories plan to offset their heavy dependence on other agencies' funding and thus only increase staff by about 10 percent through FY 1997.

The Malcolm Baldrige National Quality Award program already has experienced dramatic scale-up from its establishment in late 1987 by Congress to its first awards the next year to a full-scale program with national and international impact. With pressing needs to move quality management principles into the practices of education and healthcare organizations, NIST is readying pilot efforts leading to full-fledged award programs in 1996.

Each NIST program aims to accomplish objectives that depend significantly on industry's behavior, capabilities, and commitment.

The need to measure returns on taxpayer investments in federal technology programs is of paramount importance.

carefully and rely on measures of performance and short- and intermediate-term results as it decides where and how to invest its resources.

In addition, methodologies for measuring economic impact are still evolving, and data-collection efforts confront several obstacles: the proprietary nature of certain information, the necessarily qualitative nature of some types of impacts (for example, the adoption of quality strategies or changes in the horizons and composition of corporate research portfolios), the high cost of collecting original data, and the difficulty in clearly defining criteria for quantifying job creation and job retention. Methodological and data-collection issues notwithstanding, the need to measure returns on taxpayer investments in federal technology programs is of paramount importance, and approaches to meeting this need warrant thoughtful—but action-oriented—discussion inside and outside of government.

ADVANCED TECHNOLOGY PROGRAM

One of the most innovative elements of the NIST technology strategy, the ATP invests directly in the nation's economic growth by supporting enabling technologies with strong potential for U.S. economic benefit.

The ATP provides funds for the early phases of technology development through cooperative research agreements to single businesses or industry-led joint ventures and research consortia. There are some legislated limits. Awards to individual companies may not exceed \$2 million, and the projects must be completed within three years. Projects by joint ventures may run as long as five years, and the ATP can fund up to 50 percent of the project. Cost sharing is required for all projects.

ATP projects are selected on the basis of a rigorous competition that considers both the technical and business merits of the proposals. One of the unique features of the ATP is this review process, which evaluates the proposal's potential economic impact, the evidence that the proposer is significantly committed to commercializing the results of the project, and other business-related factors affecting the likelihood that successful results will be commercialized.

The nature of the ATP poses unique challenges for effectively setting priorities and evaluating the results of the program:

- ◆ The potential ATP client base—effectively all of U.S. industry—is huge and diverse, covering all areas of technology and ranging from small entrepreneurial start-ups to major multinational corporations. The ATP relies on substantial input from this diverse industrial base to define and implement its programs. The challenge is to run a program that responds effectively to the priorities of this heterogeneous community.
- ◆ The time line for ATP payoff is relatively long. The ATP does not support product development, but rather the development of key technologies that *enable* innovative new or improved products, services, and industrial processes. While the goal of the ATP is to foster significant economic benefits for the United States, the greatest benefits will flow from products, services, and processes that will be developed *after* an ATP project itself is completed. The challenge is to set up an evaluation strategy that considers both the immediate performance of the program and its effectiveness in the long run.

The ATP relies on substantial input from this diverse industrial base to define and implement its programs.

Setting ATP Priorities

A central tenet of the ATP since its inception in 1990 always has been that its research priorities should be set by industry rather than the government. The purpose of the program is not to impose government's judgment of the best opportunities for commercial success, but rather to enable industry to pursue certain high-risk projects that, if successful, would enable significant economic benefits for the country. U.S. industry invests tens of billions of dollars annually to turn "technology" into products, profits, and jobs. The relatively minor funding from the ATP is meant to extend industry's reach, to foster riskier projects that would not be pursued by private funds alone.

During the pilot phase of the ATP, NIST held general competitions for ATP funding, open to all areas of technology. All project *ideas* come from industry. Candidate projects are not evaluated on the basis of *what* technology is proposed, but on how sound the proposal is within that technology and on the projected economic impact. Specifically, proposals are evaluated on:

- ◆ scientific and technical merit;
- ◆ the potential broad-based economic benefits;
- ◆ plans for eventual commercialization of the research;
- ◆ the experience and qualifications of the proposer; and
- ◆ evidence of the proposer's level of commitment to the project, and clarity and appropriateness of the proposer's management plan.

As it grows from a pilot program to a full-scale activity, the ATP requires a more sophisticated approach to setting investment priorities. Even at the Administration's proposed funding level of \$750 million per year by 1997, the ATP will represent less than one-half of one percent of the nation's R&D budget. To obtain maximum benefit from its investments, the ATP will devote the bulk of its funds to selected, focused *program areas*.

ATP focused programs will have aggressive, well-defined technological and business goals, generally involving the parallel development of a suite of interlocking R&D projects. By managing groups of projects that will complement and reinforce each other, the ATP will be able to have the greatest possible impact on technology and the economy.

The key to this plan is a system for selecting program areas that retains the strong industry orientation of the ATP. The approach is analogous to that used in *project* selection: let the ideas come from industry and select on the basis of clear evaluation criteria.

ATP focused programs will have aggressive, well-defined technological and business goals, generally involving the parallel development of a suite of interlocking R&D projects.

The criteria for selecting focused program areas for ATP investment resemble those used for project selection:

- ◆ potential for U.S. economic benefit;
- ◆ strength of the technical ideas;
- ◆ evidence of strong industry commitment; and
- ◆ the opportunity for ATP funds to make a significant difference.

ATP competitions within the focused programs will support specific *projects*, using the same procedures and selection criteria used for general competitions. While most of the ATP's resources in the future will go to specific focused programs, the ATP will continue to hold general project competitions open to any and all areas of technology, holding the door open to promising ideas that don't fit into any current program. (See Reference 2 for a complete description of the process being used to define focused programs and to solicit program ideas.)

ATP Evaluations

From its start, the ATP has emphasized detailed evaluation as critical to an effective, results-oriented program. The evaluation plan for the ATP as a program has five principal elements and stresses *measurable* goals whenever meaningful:

- ◆ assessing the ATP's own critical operational activities;
- ◆ "portfolio" profiles of applicants, recipients, technologies, and projects;
- ◆ evaluation of industry's implementation of both the R&D and business components of ATP projects;
- ◆ tracking short-term and intermediate project results; and
- ◆ measurement of long-term economic impacts.

There is one important overriding consideration: The ATP does not expect every project or program to be a success. The ATP is supposed to foster *high-risk* projects that would not be undertaken without its support. In fact, too high a technical success rate would suggest that the project selections are overly conservative. Thus, ATP's success must be evaluated from the perspective of portfolio management, for which the key measures are aggregate returns on the full set of ATP-funded technologies.

Performance of critical operational activities is a measure of the ATP as a service organization. To be effective, the ATP must work smoothly with private

From its start, the ATP has emphasized detailed evaluation as critical to an effective, results-oriented program.

The ATP sponsors third-party studies of award recipients to get customer feedback.

industry and, like industry, must be agile and responsive to a rapidly changing technological frontier. Operational activities include:

- ◆ soliciting and evaluating proposals;
- ◆ promoting a widespread understanding of the ATP and its opportunities;
- ◆ providing constructive feedback to proposers whose projects were not selected;
- ◆ providing additional support to selected projects, by initiating links to related research programs, for example; and
- ◆ monitoring the progress of projects.

Typical questions include: How well known is the ATP in industry? Is industry responsive to ATP solicitations? What steps are taken to ensure high-quality proposals to the ATP? How thorough is the review process? And—very important—how do the program's immediate customers—the companies the ATP works with—view it?

Considering the relatively low levels of funding in its first three years as a pilot program, the ATP has engendered a particularly strong favorable response from industry. In four competitions, the ATP has received nearly 1,000 applications, performed more than 2,000 technical evaluations and more than 700 business evaluations (only the highest-scoring proposals in the technical evaluation go on to a business evaluation), and made awards to nearly 90 projects.

In addition to numerous talks and briefings by ATP personnel around the country, four conferences have been sponsored to help potential applicants with the fine points of the proposal process. Oral "debriefings" have been made available to all unsuccessful applicants.

The ATP sponsors third-party studies of award recipients to get customer feedback. Comments on interactions with the ATP staff have been uniformly positive. For instance, the vice president of a small company stated, "The personnel within the ATP have been the most responsive of any government organization that I have dealt with over the years. This is extremely critical. The commercial markets in technology-related fields move very fast, and a needless delay can kill a promising technology or leave it to be taken over by foreign competition."³

Profiles of applicants, recipients, technologies, and projects enable the ATP to assess how well it meets goals of reaching a broad spectrum of technologies and stimulating private R&D. Typical questions include: Can small businesses compete effectively for ATP awards? How does the ATP affect R&D trends in private industry? What technologies tend to receive the most awards? What is the geographic distribution of ATP participants? How do the ATP projects reflect critical national technology goals?

Analyses of the projects funded to date suggest that small businesses in fact do very well in the ATP. More than 60 percent of all successful single applicants are small businesses, and small businesses are playing a critical role in 18 of the 23 ATP joint ventures, including leading six of these projects.

Profiles also suggest that the ATP has led—as desired—to an increase in joint research and development ventures in private industry. In the first four competitions, approximately 125 joint ventures involving over 800 organizations were formed to apply to the ATP.

While the ATP has demonstrated considerable breadth in its pilot phase, with projects from fields such as manufacturing processes, medicine, pollution abatement, transportation, energy conservation, and even agricultural pest control, proposals have been concentrated in certain areas: information technologies (including electronics), advanced materials, manufacturing processes, and biotechnology. ATP projects can be found in every subcategory of the “critical technologies” list prepared by the Office of Science and Technology Policy.

Evaluation of industry's implementation of both the R&D and business components of ATP projects tracks how well businesses follow through on the business and commercialization strategies outlined in their ATP proposals. NIST considers this an important element, because financing research for its own sake is *not* a goal of the ATP. It also encourages the award recipient to constantly re-evaluate the commercial opportunities opened up by ATP research in rapidly changing technologies, and allows ATP managers to understand how business strategies change as projects evolve.

ATP project managers collect the information during quarterly, year-end, and end-of-project reviews. The ATP is field testing a new, customizable, questionnaire designed to gather more detailed data than are now available. A key goal is to gather the information in a manner that allows for easy updating and minimizes the reporting burden.

Tracking short-term and intermediate project results provides an indication of the ATP's immediate effect on the companies that participate. A number of measurable short-term effects are expected to provide indicators of long-term economic success. In addition to straightforward tracking of technical milestones, these indicators include:

- ◆ increased R&D investment and R&D in new areas leveraged by ATP funds;
- ◆ increased industrial collaborations and strategic alliances;
- ◆ strengthened technological infrastructure (through the development of new enabling technologies);

Evaluation of industry's implementation of both the R&D and business components of ATP projects tracks how well businesses follow through on the business and commercialization strategies outlined in their ATP proposals.

A third-party survey of early ATP award recipients found that the participants cited the ability to pursue promising lines of research that they otherwise could not have followed as the most important effect of the ATP.

- ◆ shortened R&D cycles;
- ◆ investment in production capacity; and
- ◆ productivity improvements.

A variety of tools are used for these analyses, including data gathered by ATP project managers, studies done by participating companies, and third-party reviews and surveys conducted as part of the ATP evaluation program.

After four competitions, the ATP has committed to \$247 million, leveraging approximately \$268 million in industry investment in R&D. Early results from this pilot phase of the ATP indicate that the program is making an impact.

In addition to the increase in industrial joint R&D ventures noted above, a third-party survey of early ATP award recipients found that the participants cited the ability to pursue promising lines of research that they otherwise could not have followed as the most important effect of the ATP.³ Forging new relationships between companies, and between companies and government or academic labs, was rated by participants as the second most important effect of the ATP.

Another third-party study found that total U.S. R&D work on advanced technologies for printed-wiring boards (PWBs) essential to all modern electronic devices more than quadrupled as a result of the ATP.⁴ As a direct result of the ATP, major research consortia have been formed to pursue advanced technologies in mass data storage and flat-panel displays, two technologies considered key to future information technologies. Other consortia have been funded in the areas of biotechnology, automated manufacturing, and advanced materials.

ATP participants also have cited dramatic reductions in development time and significant productivity gains—participants in the PWB project estimated average productivity gains of 30 percent in major program areas.

Long-term economic impact is the bottom line for the ATP, and its measurement is key. Program goals include increased U.S. economic growth, increased industrial competitiveness, and creation of high-value jobs. Measures of the long-run success of the ATP include:

- ◆ creation of new industries or new industrial capabilities;
- ◆ improvements in manufacturing costs, product quality, and time to market;
- ◆ increased worldwide market share;
- ◆ job creation; and
- ◆ private and social rates of return on investment.

At present, it is too early to measure long-term impacts. Several products incorporating the results of ATP-supported research have been introduced or are near

commercialization. In addition, one company has introduced ATP technology into a manufacturing process on a pilot scale, but in general almost all ATP projects are still in the R&D phase of product development. In most cases, it will take several years before a long-term effects study will be feasible.

The planned approach to these long-term studies is to use microeconomic case studies to estimate specific benefits and costs of new technologies developed under the ATP. This approach is in line with generally accepted economic analysis techniques. Specific projects and programs for detailed study will be selected using statistical sampling techniques.

The measurement of long-term economic impacts of the ATP requires three major efforts:

- ◆ development of quantitative measures of the degree of influence or effect that the ATP has on the introduction and diffusion of each new technology it supports;
- ◆ development of quantitative and qualitative measures of the influence or effect of each ATP-funded technology on the economy; and
- ◆ estimation of private and social aggregate economic benefits and costs from each new technology developed under ATP funds.

The planned approach to these long-term studies is to use microeconomic case studies to estimate specific benefits and costs of new technologies developed under the ATP.

NIST LABORATORY PROGRAMS

As noted in a recent report by the Office of Technology Assessment, NIST's laboratory program occupies a "unique niche in the nation's infrastructure."

NIST's eight laboratories serve all sectors of U.S. industry through tightly focused research programs and services that address industry's needs for measurement and infrastructural technology. Industry traditionally underinvests in the development of these infrastructural technologies because they are used simultaneously by many firms and typically are not embodied in products, making it difficult for individual firms and even industries to recover R&D investments. However, measurement methods, evaluated data, process models, interface standards, and other types of infrastructural technologies are pacing factors in technology development and application, setting the upper limit on what can be accomplished in the laboratory or on the factory floor.

As noted in a recent report by the Office of Technology Assessment, NIST's laboratory program occupies a "unique niche in the nation's infrastructure." The report also characterized the program's core competency and preferred problem-solving approach:

NIST has earned a worldwide reputation for impartiality and technical excellence. Its competencies in metrology—the science of measurement—span a number of disciplines. The efficiency of solving a measurement problem once at NIST and then disseminating the results throughout the whole industry, rather than each company performing the job independently for itself, provides outstanding leverage for NIST's metrological development.⁵

NIST's evaluations of industry's technology needs indicate widespread demand for enhanced measurement capabilities, and industry's own analyses concur. For example, a 1993 assessment by the Semiconductor Industry Association (SIA) identified unmet measurement needs as impeding the U.S. semiconductor industry's progress toward accomplishing critical technology goals. SIA called on NIST for increased assistance, describing the agency as the "only place in the U.S. where the broad range of measurements needed for semiconductor processing are routinely and systematically developed."⁶

Similarly, the Council on Radiation Measurements, which represents more than 150 U.S. companies, asked NIST to improve the accuracy of measurement standards for optical and infrared radiation by a factor of 10. The request was motivated by the companies' desire to improve quality control in a variety of manufacturing processes. The collaboration has produced a cryogenic radiometer that is possibly the most accurate in the world and is being tested in a number of applications.

Setting Laboratory Priorities

NIST's laboratories set their priorities in consultation with industry in accordance with six guiding criteria:

- ◆ the magnitude and immediacy of industrial need;
- ◆ the degree of correspondence between a particular industrial need and NIST's mission to develop infrastructural technologies;
- ◆ the opportunity for NIST participation to make a major difference;
- ◆ the nature and size of the anticipated impact resulting from NIST's participation;
- ◆ NIST's capability to respond in a timely fashion with a high-quality solution; and
- ◆ the nature of opportunities afforded by recent advances in science and technology.

NIST's laboratories try to anticipate the measurement and other infrastructural technology needs of industry. The ideal is to have solutions available before prospective problems and challenges materialize as actual obstacles in product development, manufacturing, market transactions, or other industrial and business activities. If NIST does not respond early to looming technological hurdles, the effectiveness of its laboratories is diminished. Therefore, failures to anticipate major technology needs also must be taken into account as the laboratories' priority-setting performance is reviewed.

In their strategic planning, the laboratories employ a variety of formal and informal mechanisms for soliciting industry input and gauging its priorities. Formal mechanisms include NIST-convened conferences devoted to eliciting and synthesizing company and industry-wide views on key technical challenges and major goals in important technology areas. In 1993, 40 priority-setting conferences were convened to address topics ranging from "green" manufacturing technologies to technical issues in network security.

Over the past two years, a series of conferences focused on measurement needs arising from tightening dimensional tolerances in manufactured products from integrated circuits to aircraft. Responding to the needs voiced by representatives of the \$15 billion U.S. gear manufacturing industry, NIST joined with the American Society of Mechanical Engineers and the Department of Energy's Oak Ridge Y-12 plant to create a NIST/DOE Center for Gear Metrology at the Y-12 facility. The unprecedented interagency collaboration is now under way.

Other formal mechanisms for assessing industry priorities include the agency's Visiting Committee on Advanced Technology, an advisory body primarily composed of industry representatives. Industry also is well represented on independent

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assessment panels. Organized by the National Research Council, these panels annually review the performance of each NIST laboratory and evaluate its short- and long-term goals.

Each laboratory has cultivated strong working relationships with industrial, trade, and professional organizations in its areas of technology concentration. The program of NIST's Building and Fire Research Laboratory, for example, is guided by a prioritized research agenda developed by volunteer experts from the building and fire communities under the auspices of the National Institute of Building Sciences. NIST personnel also participate actively in industry-organized technology-planning exercises. Recent examples include the Semiconductor Industry Association's initiative to develop a comprehensive technology road map and the 21st Century Manufacturing Enterprise Strategy Project.⁷

The laboratories also solicit industry input through formal surveys and through reviews of NIST-prepared planning documents and needs assessments. In early 1993, the Electronics and Electrical Engineering Laboratory issued a definitive assessment of measurement needs in nine fields of electronics technology. Developed in consultation with industry, the 448-page document, *Measurements for Competitiveness*, identifies high-impact measurement capabilities that are widely needed by the U.S. electronics industry but are beyond the resources of individual companies to develop.⁸ It serves as explicit guidance for setting the laboratory's priorities.

Other means of assessing industry's infrastructural technology needs include:

- ◆ visits to companies;
- ◆ participation on more than 800 national and international standards committees;
- ◆ measurement "round robins," which provide a comparative basis for assessing the current state of measurement practices employed by industry and for identifying key technical problems;
- ◆ joint demonstrations and experiments to identify problems and requirements for supporting technology;
- ◆ regular researcher-to-researcher interactions; and
- ◆ participation in consortia, including the 13 cooperative arrangements organized by NIST and those organized by other groups, such as PDES Inc. and the Semiconductor Research Corp.

NIST has found it necessary to use this complete set of tools to determine industrial needs. Workshops, conferences, and surveys provide valuable information on an industry, but this information usually is not complete or specific enough to be the sole basis for program planning. In turn, company visits,

participation on standards committees, "round robins," researcher-to-researcher interactions, and participation in consortia offer insight into specific company needs, and they afford the additional advantage of directly involving NIST researchers, who provide their peers from industry with a direct link to the agency's programs and projects. Thus, combining information that is specific to firms and information that can be generalized to an industry or even groups of industries is necessary to develop a balanced view of challenges facing the private sector and of the relative importance of each challenge. To assure that the proper balance has been reached, NIST publishes its planning documents for review by outside panels and by industry.

This planning process is continuous, involves most of NIST's professional staff, and provides a wealth of useful information. In developing a new program in magnetic engineering, for example, staff of the Chemical Science and Technology Laboratory solicited the views of experts at more than 50 companies and universities to identify the critical technical obstacles perceived as impeding the development and application of new thin-film magnetic materials.

Another example demonstrates how this approach is used in planning consortia. In 1991, members of the Materials Science and Engineering Laboratory visited aerospace industry companies to acquire first-hand information on problems encountered in the precision casting of metal alloys. Analysis of this information guided planning for a meeting, co-sponsored by the Aerospace Industries Association, to explore the merits of forming a consortium to improve the precision casting process. A subsequent meeting, attended by industry, university, and government representatives, resulted in a detailed technical research plan addressing issues in key processing areas and defining deliverables in forms usable by industry. Subsequently refined, that plan is now being carried out by a NIST-led consortium involving seven manufacturers, seven universities, and three federal laboratories. The effort is a distributed, cooperative undertaking, with NIST and other members performing in-house research to accomplish agreed-upon tasks that will contribute to accomplishing the consortium's four major objectives.

NIST's iterative approach to planning and priority setting enables it to respond quickly to new developments and opportunities. A clear picture of industry's needs also helps laboratory managers to determine when it is appropriate to terminate programs and reallocate scarce resources to address new, higher priority problems that have emerged. For instance, the Physics Laboratory terminated a project to provide reaction-rate data for fusion reactors and reassigned the technical staff to work on plasma-processing issues relevant to semiconductor manufacturing, which led to a productive collaboration with SEMATECH.

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Short- to Medium-Term Measures of Performance

Customer feedback, gathered through a variety of mechanisms, is the laboratories' principal source of evaluative information.

NIST laboratories use a variety of measures to track and evaluate performance, including the value and utility of research deliverables and services. Customer feedback, gathered through a variety of mechanisms, is the laboratories' principal source of evaluative information.

Although each laboratory has its own procedures for monitoring performance and technical progress—and not all of the laboratories use every available tool—all set goals for individual projects, determined on the basis of perceived customer needs identified during planning and priority setting. Technical milestones are established for individual projects, and progress is evaluated internally on at least a quarterly basis. Customer feedback also is analyzed during project, group, division, and laboratory reviews, not only to assess performance and rates of technical progress but also to identify changes in customer needs that may warrant redirecting laboratory resources. Besides their own internal reviews and those conducted by NIST management, all laboratories undergo annual assessments by external panels convened by the National Research Council. These assessment panels produce written evaluations of performance, missions, and short- and long-term goals—for the laboratory overall and for each division.

NIST gathers information on its primary “products”—measurements, standards, databases, process models, and the other types of deliverables produced by its laboratory program. These deliverables usually take the form of technical information that NIST makes widely available to U.S. industry. Measures of the relevance and value of this information to industry include:

- ◆ industry attendance, comments, and level of participation at technical workshops;
- ◆ number of inquiries and requests for information;
- ◆ attendance at technical training sessions provided by NIST personnel;
- ◆ commercialization of products incorporating the results of NIST R&D; and
- ◆ application of NIST R&D results to industrial processes.

For federal laboratories, a widely—and, perhaps, overly—reported process metric is the number of cooperative R&D agreements (CRADAs) that laboratories have entered into with U.S. businesses. Because NIST has been working with industry for more than 90 years, the agency was quick to embrace CRADAs as an additional tool for working with industry. Across the federal government, NIST has the highest ratio of CRADAs per number of technical staff and, by far, the shortest average time for processing agreements. According to *Science* magazine, “Only

the National Institute of Standards and Technology, created to work with the private sector, appears to be doing what Congress intended. ...[O]nly NIST appears to have managed to embrace CRADAs without getting smothered.”⁹

CRADA tallies, however, are an incomplete measure of performance—just as the numbers of patents received and licenses issued do not capture a technology organization’s full technical output and level of innovation. CRADAs represent but one mechanism for working with and addressing the technology needs of U.S. industry—effective for accomplishing some technical objectives, but inappropriate for others. In fact, most forms of NIST-provided technical assistance are non-proprietary (used by many firms) and are best accomplished without the formality of a legal contract.

Other measures and information used to assess industrial relevance, performance, and productivity of laboratory activities include:

- ◆ level of industry commitment to NIST projects and consortia (e.g., number of participating companies, number of visiting researchers assigned to NIST, value of resources committed);
- ◆ number of guest researchers from industry;
- ◆ extent of NIST’s contributions to industry’s voluntary standards (e.g., number of standards incorporating NIST’s work, number of memberships on standards committees);
- ◆ number of joint industry-NIST “round-robins”; and
- ◆ number of repeat customers.

Measures of Long-Term Impact

In the early 1980s, NIST initiated a series of periodic assessments of the economic impacts of NIST research.^{10–13} Conducted by independent researchers under contract to NIST, these third-party assessments have estimated the aggregate rates of return (also referred to as social rates of return) on work addressing infrastructural technology needs of industry. Returns on NIST work in the six technology areas evaluated thus far range from 63 percent to 423 percent, greatly exceeding the average rate of return on private-sector innovations and the rates reported in the few studies of other government research programs. To economists, this disparity implies underinvestment in R&D aimed at developing measurement methods and other infrastructural technologies.

An example is NIST’s work supporting the U.S. optical fiber industry.¹¹ NIST-developed measurement technologies served as the basis for more than 20 industry standards that have helped reduce market transaction costs arising from disagreements between optical fiber manufacturers and their customers. The standards established a solid basis for evaluating the technical performance of

Third-party assessments have estimated the aggregate rates of return on work addressing infrastructural technology needs of industry.

NIST also is placing increased emphasis on tracking how companies and industries use specific services and the results of specific R&D projects.

fibers. The social rate of return was estimated to exceed 400 percent, and one manufacturer has credited the standards with significantly expanding the size of the market for optical fibers.

In addition to the series of case studies of economic impact, which is continuing, NIST also is placing increased emphasis on tracking how companies and industries use specific services and the results of specific R&D projects. For example, the Visiting Committee on Advanced Technology studied the commercialization of NIST innovations that have won "R&D 100 Awards" in the annual competition sponsored by *Research and Development* magazine. Between 1973 and 1990, NIST won 71 R&D 100 Awards; about three-fifths of the innovations (41) achieved commercial impact.¹⁴ NIST also has begun to prepare a series of brief "industrial impact statements" that are intended to capture the nature of the laboratories' assistance to companies or industrial sectors, including resulting improvements in products or services, processes, and market performance, as well as jobs created.

MANUFACTURING EXTENSION PARTNERSHIP

The Manufacturing Extension Partnership, or MEP, is a growing nationwide network of manufacturing extension services that provides small and medium-sized U.S. manufacturers with technical assistance as these firms modernize their operations to increase their competitiveness. Comprising the core of the nation's manufacturing base, the more than 370,000 U.S. manufacturing establishments that employ fewer than 500 people often are, as characterized in a recent National Research Council study, "operating below their potential. Their use of modern manufacturing equipment, methodologies, and management practices is inadequate to ensure that American manufacturing will be globally competitive."¹⁵

A variety of obstacles hinder small and medium-sized manufacturers' modernization efforts. Those that impede the adoption of appropriate modern technology and organizational methods include lack of resources and in-house technical expertise, limited awareness of changing manufacturing technology and its applications, and difficulty in locating unbiased sources of information and technical assistance. Viewed from a national perspective, currently available public and private sources of assistance—which range from large companies' supplier-improvement programs to small, local industrial outreach programs and private-sector consultants—are fragmented and vary greatly in breadth and depth of services. Collectively, they reach only a small fraction of small and medium-sized manufacturers whose existence is threatened by continued reliance on outdated technology, production techniques, and management practices.

By providing leadership and building a national framework for the *delivery* of manufacturing extension services, NIST's MEP will organize a comprehensive, yet locally responsive, system to help small and medium-sized manufacturers upgrade their equipment, techniques, and operations. From a base of seven regional Manufacturing Technology Centers (MTCs), established between 1989 and 1992, the MEP is planned to grow to over 100 extension centers by 1997. Linked by a coordinating national infrastructure, each center and each partnering organization will be an entry point into an integrated network of technical resources, services, and expertise on topics ranging from computer-aided design and manufacturing to just-in-time inventory methods to workforce training.

The evolving MEP network has several components:

- ◆ regional MTCs, or MTC-like service providers, located in areas of high manufacturing density;

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- ◆ Manufacturing Outreach Centers, or MOCs, which serve areas of lower manufacturing density, either as free-standing entities or as MTC satellites;
- ◆ the State Technology Extension Program, or STEP, which provides funding and technical support for planning, implementation, and regional linkages to strengthen industrial extension efforts in the states; and
- ◆ "LINKS," which encompasses the national structure of communications, data systems, evaluation, field-agent training, tool development, and linkages with technology sources.

NIST's MEP staff have played a key role in the review and merit-based selection of winners of deployment awards made under President Clinton's Technology Reinvestment Project (TRP), which is managed by the Defense Department's Advanced Research Projects Agency. NIST is managing 42 of the 70 TRP deployment activities selected to date, and these activities will be incorporated into the manufacturing extension network. Recent TRP award winners include 22 new centers that will enable NIST to accelerate development of the MEP network.

Setting Priorities

Guiding Principles. The design and evolution of the national manufacturing extension network are guided by several basic principles that broadly define the MEP's priorities, operational and organizational philosophies, scope of services and activities, and strategic emphases.

First, all recipients of MEP funding are *selected through merit-based competitions* that assess how fully each candidate satisfies the criteria established for each component of the network.

Second, service providers in the MEP network *tailor assistance and technology solutions to the needs and constraints of client firms*, including budgets and workforce capabilities. The providers are client-driven, not provider-driven.

Third, extension centers and other components of the MEP network are *not supported to perform manufacturing R&D*, concentrating entirely on the diffusion of appropriate technologies to speed industrial modernization.

Fourth, the MEP is *inclusive*, and it *prevents duplication* of effort by emphasizing a network design that takes maximum advantage of the knowledge, experience, and expertise of a broad spectrum of existing organizations.

This principle yields two other, closely related characteristics that are key:

- ◆ The network is non-hierarchical. It builds on grassroots proposals motivated by and tailored to the needs of local industry and allows local

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flexibility and innovation in addressing those needs, while providing the technical support and resources of a national infrastructure.

- ◆ The MEP does not compete with private technical consultants; it recognizes the important role that these consultants play in helping small and medium-sized manufacturers improve their operations. The NIST MTCs have developed constructive relationships with private consultants, who can help the centers extend their reach and broaden the range of technical assistance and expertise accessible through the MTCs. At the same time, in many cases, MTC activities help private consultants expand their reach by qualifying small manufacturers and helping them understand the value of consulting services. To ensure a clear understanding of this relationship and to avoid potential conflicts, MEP staff are now evaluating how private consultants serve small manufacturers and what role the MTCs play in that process.

Selection Criteria. Separate selection criteria have been developed for each MEP component, although there is substantial overlap because of shared objectives. All centers and projects are selected only after undergoing competitive review. The criteria used to evaluate proposals for new centers are representative:

- ◆ *Knowledge of target firms:* Comprehensive understanding of an area's manufacturing base, including business size, industry types, product mix, and technology requirements.
- ◆ *Technology resources:* Linkages to external sources of technology, including educational institutions, state and regional technology transfer programs, and federal laboratories.
- ◆ *Delivery mechanisms:* The staff, resources, and methodology for effectively delivering appropriate manufacturing technologies and techniques to local or regional manufacturers, as well as the ability to form effective partnerships with other organizations offering complementary services or resources.
- ◆ *Management and financial plan:* An effective management structure, full-time top management, additional sources of funds, and an effective system of internal evaluation.

Program Evaluation

In preparing for the MEP's expansion, staff members are developing a strategic plan that integrates the functions of each service-delivery component of the network and lays the methodological foundation for evaluating program performance and measuring results. A national, standardized system of data collection

MEP builds on grassroots proposals motivated by and tailored to the needs of local industry and allows local flexibility and innovation in addressing those needs, while providing the technical support and resources of a national infrastructure.

A national, standardized system of data collection and evaluation will enable MEP staff to assess the efficiency and effectiveness of the entire network.

and evaluation will enable MEP staff to assess the efficiency and effectiveness of the entire network, each network component, each type of extension service, and each service provider. The evaluation system will identify the services most valued by small and medium-sized manufacturers; characterize the types of firms and industries that make the greatest use of manufacturing extension services, as well as those that make the least use of services; prevent duplication of effort; and measure economic impact at levels ranging from individual services and centers to the MEP as a whole.

Measures of Organizational Performance. All MEP organizations are required to submit detailed quarterly and annual reports, standardized for each of the four components of the network, and they undergo annual performance reviews by MEP regional managers. At the end of the third year of operation, extension centers undergo rigorous evaluations by outside panels appointed by NIST.

Reported quarterly by each center, the following types of information help MEP management to evaluate overall performance of the MEP organizations and to assess market penetration (i.e., number of client firms relative to the size of the potential client base), the mix of services provided, the breadth and depth of organizational linkages, and the ability of the center to generate revenue to support operations:

- ◆ staff composition and percentage of employees working with clients in the field;
- ◆ number of establishments served, by size;
- ◆ ratio of the number of technical assistance projects proposed to client companies to the number initiated;
- ◆ number of activities initiated, by type of activity (e.g., formal assessment, technical assistance project, initial site visit, information referral), technical focus (e.g., control systems; plant layout; computer-aided design, manufacturing, or engineering), and size of firm;
- ◆ number of participants and number and types of firms represented at training programs and other events; and
- ◆ results of client valuation surveys.

Upon completing technical assistance projects, the centers ask client firms to assign values to the services provided. Clients estimate the impact that the just-concluded project will have on company performance over the next 12 months.

Specifically, firms are asked to estimate the anticipated impact of the project on sales, costs, capital spending, inventory levels, and jobs (number created or saved). Although subjective, these measures provide center management and personnel with the means to ascertain levels of customer satisfaction and to

differentiate among clients' perceptions of the type and magnitude of benefits attributable to center activities.

MEP management fully appreciates the importance of measuring performance, but it also recognizes the need for flexibility in reporting formats, particularly for pilot projects that are testing experimental services and service-delivery mechanisms. Overly rigid process and outcome measures could yield data that provide little meaningful information for evaluations of performance and impact and, at the same time, inhibit experimentation and innovation. Successful "LINKS" and extension enabling TRP projects, for example, may provide services that indirectly affect manufacturers but directly improve the quality and accessibility of information and services provided by extension centers. Measures of performance and results are being developed for these kinds of activities, with the recognition that what gets measured gets emphasized and that not all measures are equally significant for all types of activities and MEP components.

Measures of Economic Impact. In addition to evaluating the performance of each extension center, NIST also measures each center's specific impact on client companies. In contrast to the ATP and NIST's laboratory programs, the MEP is expected to generate economic benefits within a short time span. Indeed, MTC client firms reported substantial benefits, including cost savings, higher productivity, and increased earnings, within the first year of each center's operation.

Though necessarily small in scope because of the limited scale of manufacturing extension efforts undertaken thus far, the results of analyses—supplemented by case studies and other anecdotal evidence—illustrate the large potential for significant economic and company benefits.¹⁵⁻¹⁸ Cumulatively valued and based on self-reported data from MTC client firms, company-realized benefits from formal MTC technical assistance projects totaled an estimated \$320 million between 1989 and 1992, translating into a return of over \$7 on each federal dollar invested in the centers. This estimate undervalues the impact of some MTC services, such as seminars and information referrals. Many firms consider these "soft" services to be very beneficial, even though their impact is difficult to quantify.

For the network's individual extension centers, as well as for the MEP as a whole, the fundamental unit of analysis is and will continue to be individual firms. On an annual basis, the MTCs also administer questionnaires to ascertain the progress made by client firms. One year after the completion of a technical assistance project or other substantive interaction with a center, client firms are asked to assess their progress and business health by comparing information in key performance areas one year before and one year after projects have been completed. The before-and-after assessment considers three levels of outcomes, which will be analyzed in relation to a "control" group.

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Base-level client outcomes serve as indicators of how successfully centers are assisting firms in adopting appropriate technologies and management practices.

Base-level client outcomes serve as indicators of how successfully centers are assisting firms in adopting appropriate technologies and management practices; making more use of capital, labor, and materials; and improving response time and other key aspects of manufacturing performance. These measures are:

- ◆ changes in scrap rate (value of scrap per sales—an indicator of quality and of efficiency of material use);
- ◆ changes in computer use (percent of employees using computers or programmable machine controllers at least weekly—an indicator of broadening applications of computers, the essential element of many new manufacturing and business technologies); and
- ◆ changes in inventory turns (ratio of sales to inventory—an indicator of increasing throughput, which may be the result of improved layout, scheduling, and routing).

Intermediate-level client outcomes are designed to reflect changes that stem from performance improvements at the base level of operations, although these changes may take longer to materialize. These include:

- ◆ changes in the ratio of sales per employee—an indicator of increased labor productivity; and
- ◆ changes in manufacturing lead time—an indicator of decreased response time to customer orders.

Top-level client outcomes reflect business and employment gains traceable, at least in part, to operational improvements captured by the previous categories of measures. Among the outcomes measured are:

- ◆ change in total sales,
- ◆ change in export sales,
- ◆ change in employment, and
- ◆ change in employee income (payroll per employee).

Although these objective outcome measures may not correspond directly to the extension services provided, they are easily tracked by client firms, and they have the virtue of being related, at least indirectly, to the substance and aims of most service activities. As they come on line, all MEP service providers will be required to submit client progress reports based on surveys to ascertain the performance of firms in the years before and after completion of an extension service activity.

The MTCs are currently collecting 1990 and 1992 data from firms that they assisted in 1991. Results of client progress surveys of 28 firms assisted by the Great Lakes MTC in 1991 are illustrative.¹⁶ For example, the firms reduced their

manufacturing lead times by an average of 22 percent and reported average increases of:

- ◆ 13 percent in sales,
- ◆ 47 percent in value of exports,
- ◆ 6 percent in employment,
- ◆ 17 percent in total payroll, and
- ◆ 46 percent in the use of computers or computer-controlled equipment by employees.

To increase the value of the data gathered in client progress surveys, the MEP is developing a nationwide benchmarking database on the performance of up to 1,000 plants to help companies better understand their competitive position in the marketplace. The database will build on a 300-client database developed by the Midwest MTC in Ann Arbor, Mich., which now contains performance data for five industries. This will enable the Midwest MTC to provide benchmarking service to client firms of other extension services. In addition, the expanded database will be a useful MEP management tool, enabling national-level comparisons of the performance of MEP clients with the performance of "control" firms that have not used extension services.

Because the MEP is promoting measurement and evaluation as powerful learning and management tools, it has asked the Modernization Forum, which draws its membership from the centers, to develop a guide on evaluation and associated training materials for use by project managers and manufacturing extension field agents. Training workshops are now being planned, with the first scheduled for February 1994.

Finally, the MEP will continue to sponsor third-party reviews of the extension network and its components to evaluate their effectiveness and to guide improvements in performance, including evaluation. It already has initiated several efforts to build a common understanding of process and outcome evaluation. For example, it has sponsored studies of evaluation issues and practices in industrial modernization programs, one conducted by the Georgia Institute of Technology and the other by Carnegie Mellon University. It also requested a National Research Council study of barriers and opportunities to improve the manufacturing performance of small and medium-sized manufacturers.¹⁵ Other steps taken to build a national framework for evaluation include the continuing development of taxonomies for classifying types of services, activities, and manufacturing problems and practices as well as efforts to form a national network of evaluators comprising federal, state, local, and academic experts.

The MEP is promoting measurement and evaluation as powerful learning and management tools.

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Session 3

Technology Reinvestment Project

Technology, the key to America's Cold War military strategy, will be even more important in the unpredictable security environment we now face. But the military must reduce its reliance on a "defense-unique" technology and industrial base in response to two new realities:

- Cold War defense budgets are no longer sustainable; affordability, along with performance, must now be a primary concern for DoD.
- Many of the technologies most critical to defense are emerging in the commercial sector; currently, defense access to these technologies is limited.

DoD's dual-use technology strategy is a response to these new realities, and the Technology Reinvestment Project (TRP) is DoD's largest dual-use technology program.

The mission of the TRP *is to give the Department of Defense greater access to affordable, leading-edge technology by leveraging commercial know-how, investments and markets for military benefit.* This mission is embodied in two strategic goals: (1) to enhance the technological superiority of defense systems while lowering costs; and (2) to strengthen the industrial base on which DoD depends while lowering its cost.

To achieve these goals, the TRP awards funds, on a cost-shared basis, to industry-led projects to create new dual-use technologies. These **technology development** projects are of two types, corresponding to the first two pillars of DoD's dual-use technology strategy.

- **Leveraging commercial technology:** The first type of project advances the commercial development of key technologies that meet defense needs. Because commercial

demand will eventually make these technologies more affordable to the military, DoD benefits by accelerating the development of the technology while simultaneously ensuring that it meets defense requirements.

- **Transitioning defense technology:** The second type of project promotes the transitioning of defense technologies to commercial applications. The creation or enhancement of commercial markets for these technologies makes them more affordable and accessible to the military.

Although the lion's share of funds has gone to technology development, the TRP has awarded smaller amounts of money to projects in two other areas: **technology deployment**, to build a "dual-produce" capability in the U.S. manufacturing base, by helping small defense firms compete in commercial markets; and **manufacturing engineering education**, to reorient engineering education to the dual-use manufacturing industries of the future. Last year, the Department of Commerce assumed full responsibility for supporting technology deployment.

Winning projects are chosen solely on the basis of merit by technical evaluators from the Department of Defense and other federal agencies. To ensure that TRP projects are driven by market needs, participants must contribute at least half the cost of the project.

The TRP is implemented by the Department of Defense (ARPA and the military services), working jointly with five other agencies: the Departments of Commerce, Energy and Transportation, the National Science Foundation and the National Aeronautics and Space Administration. The FY93 budget for the TRP was \$472 million; in FY94 the program received \$404

million. The FY95 appropriation is \$443 million. The President's FY96 Budget requests \$500 million for the TRP.

President Clinton unveiled the TRP on March 11, 1993. The subsequent competition was heavily oversubscribed: the TRP received 2,850 proposals, requesting \$8.5 billion.⁸ These proposals were evaluated by 300 experts from DoD and other federal agencies. Between October 1993 and February 1994, the TRP announced awards of matching federal funds totaling \$605 million to 212 projects, involving 1,600 firms, universities and other participants. Awards went to *all* of the 1993 proposals that were "highly recommended".

In March 1994, the TRP announced 1993 Small Business Innovation Research (SBIR) awards of \$15 million to 153 small businesses.

A second TRP competition got underway in April 1994. In October, the TRP awarded \$200 million in federal matching funds, bringing to \$820 million the total size of awards

announced so far under the TRP. The awards went to 39 projects involving 224 participants.

A third TRP competition, to allocate \$415 million, was announced on October 21, 1994. DoD will announce the awards in mid-1995.

Assessing the TRP: Insights from the First Two Years

Few federal programs have been as enthusiastically received and as carefully scrutinized as the TRP. The program has received considerable praise as well as its share of criticism—much of that the result of a misunderstanding of its mission (see Box G). In response to suggestions from industry, ARPA has modified the program to increase applicants' success rate and expand participation by small business. In addition, the TRP has increased the military services' involvement in the program, to ensure that TRP-developed technologies are rapidly integrated into defense weapon systems.

⁸Industry responded aggressively to the TRP solicitation despite its complexity (eight statutory programs, each with its own requirements); the \$8.5 billion in requested funds exceeded available funds by a factor of 17 overall, and by as much as 30 or 40 for some of the technology development programs. Moreover, many of the proposals were very good: Although the TRP funded all of the "highly recommended" proposals—about 7 percent—the program was unable to fund any of a large number of proposals that were "recommended" by evaluators.

TRP Mission: Dual Use Not "Defense Conversion"

Although the Technology Reinvestment Project has completed two competition cycles and awarded more than \$800 million in matching funds, its basic mission is still not fully understood. A "defense conversion" program has the aim of converting defense firms and workers from military to civilian production; that is *not* the purpose of TRP. Rather, the TRP mission is to increase defense access to affordable, leading-edge technology by leveraging commercial capabilities and markets. The program pursues this mission in two ways, corresponding to Pillars 1 and 2 of the Department of Defense dual-use technology plan. First, it accelerates the development of emerging commercial technologies, such as flat panel displays and high-density data storage, that are critical to defense. Second, the TRP helps transition defense technologies to commercial applications where that will benefit DoD.

The second approach may be confused with "defense conversion," but the differences are key. The TRP's customer is the Pentagon: The program supports "spinoff" of defense technology only if it preserves access to a technology or makes it more affordable to the military. Moreover, the TRP, in effect, requires defense firms to partner with non-defense firms that have know-how in marketing and low-cost production. Experience has shown that most defense firms cannot "convert" their high-overhead, cost-plus culture to compete in commercial markets. Thus the most effective way to move defense technology into commercial markets is through partnerships with non-defense firms.

Some have questioned the defense relevance of TRP projects in health care, the environment and other seemingly nontraditional areas. In fact, medical technology has long been a mission interest of the military services—e.g., the Army and Navy's research in telemedicine. And environmental technology meets two important defense needs: detection of biological/chemical warfare agents, and monitoring and cleanup of contaminants at DoD sites. More generally, the process for selecting TRP focus areas, evaluating proposals and managing projects ensures that the program serves military needs foremost.

Misunderstandings about the program have led some to characterize the TRP and other dual-use technology programs as a "nontraditional" defense expenditure - that is, an expenditure that does not contribute to traditional DoD military activities. That label is incorrect for two reasons.

First, for 50 years technology has been the basis of this country's military advantage, and defense R&D has been the key to that. The TRP and other DoD dual-use technology programs represent a different—and more effective—way of carrying out certain critical defense R&D activities.

Second, dual use itself has a rich tradition in DoD, particularly ARPA, where program managers in the 1950s and 1960s consciously promoted industrial spinoffs as a way to lower the cost of technology to the military. That visionary approach later fell victim to budgetary pressures as well as political pressures to limit the Pentagon's impact on society (the word "Defense" was added to ARPA's name in 1972, as a way to restrict the agency). The Clinton Administration's support for expanded dual-use R&D—like the reinstatement of ARPA's original name—marks a return to the agency's traditional approach.⁹

⁹This history is described in a 1992 article by Admiral Bobby R. Inman and Sen. Jeff Bingaman that urges Congress, for the sake of national security, to "restore the Pentagon's traditional role of promoting technology with commercial as well as military uses." "Broadening Horizons for Defense R&D," *Issues in Science and Technology* (Fall 1992).

One indication of the TRP's success is the amount of private investment it has catalyzed. In 1993, winning projects matched every federal dollar with \$1.40 of non-federal funds—\$845 million. The cost share by 1994 winners was also significantly above the dollar-for-dollar match required by the TRP. In all, the federal TRP investment of \$820 million is leveraging projects worth \$1.9 billion. By putting private sector money at risk, the cost share also ensures industry's commitment to the project and lays the foundation for industry to assume the total cost of commercialization.

To provide more systematic feedback, ARPA and the interagency TRP Working Group are developing a formal structure to monitor and assess the impact of the program in terms of its strategic goals. Although it is too early to judge the technical progress of many TRP projects, much less their final outcome, an analysis of the proposals and awards provides a preliminary picture of the program's direction and impact.

Significant Benefits to Defense Systems

The TRP will yield *direct* benefits to the military in the form of technologies and products that the military services can use. *Indirect* benefits include cost savings, advanced commercial capabilities for military use, and preservation of the defense industrial base. (See Chart 1 for sample metrics.)

The TRP has been carefully designed to ensure that military needs are given priority consideration: DoD representatives oversee program planning, and the military services are closely involved in all aspects of program execution.

For example, for the 1993 technology development competition:

- over one-third of the TRP evaluators were from DoD;
- the military services, service laboratories and defense agencies are managing two-thirds of TRP funds;
- service laboratories and other DoD facilities are participants in 30 percent of the projects.

The most persuasive evidence of the military benefit is the projects themselves: All TRP pro-

jects meet clear defense needs, as well as contributing to the broader industrial base. Box H (below) describes some typical TRP projects; they are developing dual-use technologies to provide for affordable night vision capability, to improve battlefield casualty treatment, and to make affordable the Army's technically superior, but high-cost, system for locating combat units on the battlefield in real time. By taking advantage of the potential for a commercial market, these projects offer the prospect of technology with improved performance at lower cost to DoD.

As an overview, Chart 2 shows the number and value of 1993 technology development awards in each technology category. (These technology categories are more broadly defined than the focused technology areas in the April 1994 competition.) Three of the 1993 technology development categories contribute directly to the performance and affordability of DoD weapon system platforms: vehicle technologies (including advanced batteries), ship-building, and aerospace. These three areas received about 30 percent of available funds. (Chart 3.)

For example, Martin Marietta leads an effort to develop a new airport radar system that can detect hazardous weather conditions while simultaneously monitoring air traffic, using a technology first developed for the Navy. Commercialization of this technology for the civilian aviation market will yield better and cheaper technology to meet military needs in tactical ballistic missile defenses and airborne fire-control systems. To take another example, a Miami-based team led by Pratt & Whitney is developing lightweight, polymer composites for aircraft engines. Advanced composites will significantly increase the performance and range of military aircraft, while lowering the cost of repair and maintenance.

Dual-use process improvements—in electronic design and manufacturing, mechanical design and manufacturing, and materials and structures manufacturing—promise significant improvements in the cost of producing defense systems. (Chart 4.) For example, the Precision Laser Machining Project (Box E, above) will develop a new class of high-speed, high-precision laser machine tools with widespread application to military as well as commercial production. Among other things, these

new laser tools will make it possible to increase aircraft fuel savings by several percent, by improving the uniformity of millions of microscopic holes drilled in airframes to reduce wind drag.

Information infrastructure projects, which received 30 percent of 1993 technology development funds, directly enhance defense electronics and communications systems. (Chart 5.) The Gulf War provided a glimpse of the revolutionary potential of these technologies, which can boost dramatically the range and accuracy of conventional weapons such as bombs and missiles, and can design the next generation of aircraft, ships and missiles. In addition to reducing the cost to DoD of information technology through dual-use applications, projects in this category will improve fiber optic transmission, signal processing, radar imaging, wireless communications, and radar frequency modules. Other projects will create new dual-use capabilities such as speech-activated hand-held computers, software standards, and advanced techniques for manufacturing efficiency.

So important is information technology to the military that the April 1994 TRP competition targeted five focused technologies in the information and electronics area. (Chart 6.) One "focus area" is high-density data storage devices. Because commercial needs will eventually drive the market, DoD benefits by stimulating and accelerating that market. Vast increases in portable, low-cost data storage will allow DoD to take full advantage of the growing availability of high resolution mapping images during military operations, and will give our front-line soldiers immediate access to the best information and intelligence. Another group of projects will help ensure the creation of open, interoperability standards for the National Information Infrastructure in areas that are defense-critical. High-definition systems manufacturing technology is a third focus area: These systems (also known as flat panel displays) will be as important to American soldiers in future conflicts as two-way radios and GPS receivers were in Desert Storm.

The 1994 competition also targeted two sensor technologies. (Chart 7.) Uncooled infrared sensors, to take one, offer a potentially affordable

approach to providing night vision capability to combat troops; the widespread use of effective infrared devices on the battlefield could revolutionize our ability to fight under cover of night, fog or smoke. The devices now employed by the military require cryogenic cooling, whose cost is prohibitive for widespread use by troops. Commercial development of uncooled sensors—e.g., for police work and enhancement of vision in cars and trucks—could bring improved performance and a tenfold cost reduction for military users (see Box H, below).

Summary: Defense Benefits of "Spinoff" and "Spin-on"

Like uncooled infrared sensors, about half of all TRP projects serve defense needs by moving DoD-funded technologies into commercial applications. Despite the size and sophistication of the defense technology base, the bulk of defense R&D never leaves the defense sector to build commercial capabilities. TRP projects, as Chart 8 shows, are replete with new uses for defense technologies, from the application of amorphous silicon to medical imaging to the use of advanced composites for bridge repair. DoD benefits primarily from the lower costs achieved through more efficient production and economies of scale. In addition, some TRP projects contribute to more than affordability. For example, the work of the Precision Laser Machining Project will yield back a superior technique for jamming the sensors of heatseeking missiles.

Chart 9 summarizes the defense benefits from several TRP projects that "spin-on" emerging commercial technologies. Defense often trails in these technologies; thus the projects provide the military with superior technology that will, over time, become affordable because of the potential for a self-sustaining commercial industry. Flat panel displays and high-density data storage devices fit this pattern. Another example is technology for treatment of battlefield casualties, including digital X-Rays, sensors, and information technology. In one TRP project, General Electric has teamed with EG&G in a two-year program to develop a Digital X-Ray System for Trauma and Battlefield Applications (see Box H, below).

Improvements to Industrial Base Supporting Defense

In addition to providing direct defense benefits, TRP projects strengthen the industrial base supporting defense. The result of these investments will be a stronger and more diverse industrial base capable of making more affordable products for the military. (Chart 10.)

One way the TRP strengthens the industrial base for defense is by expanding the market for defense-dependent firms that cannot sustain themselves by military sales alone. Many of these firms have technologies and core competencies that have application in the commercial sector. Under the TRP, these firms are teamed with commercial firms that understand low-cost production and marketing, to develop viable "spinoffs" for new markets.

Similarly, the TRP is helping to preserve defense-unique capabilities that might otherwise disappear. One example is Hi-Shear Corp., a small Torrance, California, firm that makes military detonators. With the help of a TRP award, Hi-Shear, in partnership with the Torrance Fire Department, is adapting its pyrotechnic technology for use in emergency rescue equipment. By developing new, civilian markets for its technology, Hi-Shear will be able to remain a defense supplier.

Third, a number of TRP projects are spinning off defense technologies that have application to the manufacturing process itself, which enhances the industrial base for defense as well as commercial production. (Chart 11.) For example, DoD's 3D printing capability will be used to increase the precision of injection molding for ceramics, which will reduce the cost of components for commercial and military jet engines; information-related technologies will contribute to more precise computer-controlled manufacturing processes and the "paperless factory." In many cases, the original developer of the technology was aware of the commercial potential but lacked the commercial expertise and financial support that the TRP partnering process provides.

The TRP will be measured in considerable part by its contribution to breaking down the barriers that separate the civilian and defense sectors. Judging from its first two years, the program is succeeding. By design, the TRP has

attracted a broad mix of public and private participants and stimulated an enormous amount of collaboration and alliance-building, both within industry, and between industry, universities and federal laboratories. Many losing teams confided that they had gained from the process, and a number of teams said they would proceed without federal funds (albeit on a smaller scale or without as much payoff to DoD).

Most notably, TRP technology development projects bring together teams that are well-integrated, both horizontally and vertically: A typical winning team includes a large defense prime, a large commercial prime, one or more small firms, and a university or federal lab. The presence of commercial firms on most teams is particularly important, because it expands the industrial base serving DoD and ensures that the resulting technology will be commercially viable. In fact, the April 1994 TRP competition, with its emphasis on leading-edge electronics technology, produced a number of awards to teams *led* by commercial firms.

In addition, TRP teams benefit from strong participation by public and non-profit organizations, including universities, medical institutions, public and private laboratories, and government entities at all levels. (Among successful technology development projects, one-third of participants are from outside of industry.) Universities and labs are important sources of advanced technology with potential military application. Government participants often provide the perspective of a non-DoD customer for dual-use technology—as, for example, in the development of equipment for toxic waste clean-up or advanced firefighting services.

The TRP also produced an unprecedented partnership among agencies within the federal government. DoD got the benefit of the other agencies' expertise in civilian technology applications, while the non-defense agencies got valuable exposure to military technologies with potential relevance to their mission needs. For example, the Department of Transportation is now looking at increasing its funding to adapt advanced composites for construction of bridges and roads, which will help to preserve the composites industrial base and bring down the cost of those materials for military aircraft. Cooperation among the agencies

has increased outside of the TRP, as a result of their greater awareness of one another's activities in dual-use technology. Of lasting value, the civilian agencies have begun to adopt ARPA's more streamlined approach to funding R&D, including greater flexibility toward intellectual property rights.

Lessons Learned. The TRP's 1993 competition revealed two key areas for improvement: The success rate of proposals was too low, resulting in wasted bid and proposal expenditures by unsuccessful applicants. And participation by small firms was too limited.

To raise the success rate for TRP applicants, the 1994 competition targeted specific technology focus areas that are of direct military interest. Among other advantages, this targeting gave prospective applicants a better basis for deciding whether to apply. Second, the TRP conducted more outreach to prospective applicants, including day-long workshops on each technology focus area. Third, prospective teams were encouraged to submit "white papers" for review, prior to preparing a full proposal. As a result, although requested funds still exceeded available funds by a factor of four overall, the success rate of technology development proposals was 18 percent, which is more typical of other ARPA programs.

To improve the ability of small companies to participate, the TRP took advantage of new legislation permitting small firms to use SBIR grants as part of their cost share. Small firms also were given up to 120 days following the announcement of an award to come up with their share of project costs. These changes, combined with a more aggressive outreach effort to small firms, resulted in a higher participation rate: 70 percent of the 1994 development teams included one or more small firms, compared to 50 percent in 1993.¹⁰

In addition to these changes, the TRP has increased the level of involvement by the military services even more, to ensure that technologies developed with program funds are rapidly integrated into defense systems. The services played a larger role in the selection of focus areas for the 1995 competition, and they are now represented formally on the Defense

Technology Coordinating Council, which oversees the TRP.

1995 Competition. The Clinton Administration is committed to continuing and to improving the TRP. Program staff have conducted workshops around the country both to provide feedback to unsuccessful applicants and to solicit ideas for improving the program. The TRP held several two-day workshops to help participants form and maintain R&D partnerships.

The 1995 competition, announced on October 21, 1994, will allocate \$415 million in matching funds; the bulk of the money will go to technology development projects in 12 dual-use focus areas selected for their defense relevance:

- **Digital wireless communications and networking systems**—Development of innovative communications and networking products to promote the "digitization of the battlefield."
- **Affordable polymer matrix composites for airframe structures**—Development of materials and manufacturing technologies for affordable fabrication of primary airframe composite structures to improve military and commercial aircraft performance and cost-effectiveness.
- **Microelectromechanical systems (MEMS) applications**—Demonstration and insertion of MEMS technology into defense and commercial applications (inertial sensors, embedded detection devices, etc.).
- **Low-cost specialty metals processing**—Demonstration and insertion of innovative forming of component fabrication processes to make specialty metals more affordable for military and commercial use.
- **Millimeter wave products**—Development of affordable and reliable millimeter wave products using monolithic-format integrated circuits for use in military and commercial applications.
- **Electric and hybrid tactical and commercial vehicles**—Development of affordable medium-to-heavy hybrid electric drivetrains for military and commercial use.

¹⁰Overall, small firms have done best in the TRP competition as participants rather than project sponsors. This reflects DoD's strong preference for project teams that are committed to commercialization: Many small technology-oriented firms lack commercialization and production know-how, and TRP proposals led by small firms often have not included other firms with compensating expertise.

Chart 1

Sample Metrics – Defense Benefits from TRP

“Process” – Analysis of Proposals and Awards

- Level of investment in areas critical to defense
- Development of technologies that will result in defense products
- Dual-use investments that will reduce defense costs
- Increased availability/security of defense material
- Infuse military items with advanced commercial technologies

Technical Progress and Commercialization

- On time progress toward technical milestones for defense applications
- Transfer of technology and expertise within team
- Identification and coordination with potential defense customers
- Progress toward commercializing product for DoD market

Outcome – Analysis of Results

- Breadth and criticality of military applications
- Cost savings achieved through dual-use approaches
- Increases in DoD use of commercial technologies and items
- Impact of “spinoffs” on defense costs
- Preservation of defense industrial base, skills, processes and facilities

Chart 10

Sample Metrics – Industrial Base Benefits from TRP

"Process" – Analysis of Proposals and Awards

- Number of non-defense/non-traditional participants
- Defense firms maintaining viability through "spinoffs" to new markets
- Non-defense firms entering defense market through "spin-ons"
- Development of effective partnerships among diverse organizations
- Likelihood of improved health in essential defense sectors

Technical Progress and Commercialization

- Effective coordination of responsibilities among partners
- Progress toward product that responds to diverse market needs
- Transfer of knowledge and expertise between participants
- Progress toward commercialization

Outcome – Analysis of Results

- Increase in diversity within defense supplier base
- Transition to integrated facilities
- Expansion of market/improved viability of defense-dependent firms
- Increase in use of dual-use and/or commercial products by DoD
- Expansion of privately funded TRP-like activity

Appendix C

**ECONOMIC METRICS FOR TECHNOLOGY:
A SELECTED BIBLIOGRAPHY**

**Economic Metrics for Technology:
A Selected Bibliography**

I. Economic Criteria for Investment and Evaluation

a. Ex-Ante Criteria for Technology Investment

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