Advanced Manufacturing Science and Technology Initiative

March 2001

Prepared by:

National Coalition for Advanced Manufacturing (NACFAM)
2000 L St. NW, Suite 807, Washington DC 20036
T: 202-429-2220, www.nacfam.org

Advanced Manufacturing Science and Technology Initiative

Summary

To authorize funding for a 3-year, $5-billion basic manufacturing science and technology initiative to enhance productivity growth and economic prosperity.

Findings:

- Popular perceptions to the contrary, manufacturing is a critical component of the national economy, remains the most powerful engine of economic growth, and drives the technology boom.
- The technology-intensive manufacturing sector leads the nation in productivity growth, the key to increasing the standard of living and having the resources to meet the nation's multiple needs. The effective use of advanced technology enables manufacturers to produce the next generation of goods faster, better, cheaper, and cleaner than ever before.
- Past federal investment in the underlying S&T infrastructure have transformed manufacturing processes and fostered product innovation. Federal support is beginning to decline as a share of national activity. Federal basic and applied research expenditures have declined as a percentage of GDP since 1991 from 0.5 percent to 0.398 percent in 1998.
- While industry has the central role in manufacturing R&D, industry focuses on short-term product technologies. The federal role lies in supporting longer-term, basic manufacturing science and technology and those areas that are directly applicable to the needs of government programs.
- Public investment in manufacturing-related R&D is less than 5 percent of all federal R&D and is declining. Despite increased support for information technology and health-related R&D by the federal government in recent years, the scientific disciplines that support innovation in manufacturing process technologies are flat or declining. Thus, these process technologies enable non-inflationary productivity growth – the underpinning of the "New Economy" – the nation is underinvesting in the next generation of productivity-enhancing technologies.

Recommendations:

- Expand federal investment in 7 outlined research areas, including: (1) Emerging or breakthrough process technologies; (2) Intelligent controls and systems; (3) Environmental quality and energy efficiency; (4) Pervasive

modeling; (5) Interoperability of software systems; (6) Knowledge management and learning systems; and (7) Web-based design and manufacturing.

- Creation of a federal interagency committee to coordinate and oversee the investment strategy across the government, drawing representatives from the Department of Agriculture, Defense, Energy, Commerce, Transportation, National Science Foundation, National Aeronautics and Space Administration, and the Environmental Protection Agency.
- Creation of a private sector advisory council to provide advice and consultation on the content and direction of the technical agenda.
- Design procedures to incorporate industrial involvement on a case-by-case basis. Industrial participation, where necessary and appropriate, will leverage public support, provide a critical technology and knowledge transfer mechanism, and enhance the return on investment from public investment.

Introduction

Manufacturing is the cornerstone of U.S. economic growth and continued national prosperity. The rise in productivity growth by manufacturing played a significant role in propelling the high growth, low inflation economic expansion of the 1990s to record lengths, dramatically increasing the nation's standard of living. Manufacturing also consumes the technologies, software, and services that sustain the "new" and service economies, and is the determining element of the nation's global trade position.

Manufacturing today is radically different than that of the 1950s, 1970s, or even the 1980s. The belching, smokestack factories of yesteryear have been replaced by plants with advanced sensors, clean rooms, and computer-controlled processes. The dangerous, dirty, labor-intensive assembly lines are gone, replaced by advanced robotics and intelligent systems that allow remote control and diagnostics. Industries that once employed tens of thousands now have a fraction of that number because the introduction of advanced manufacturing process technologies have made plants more productive. New manufacturing sectors, like semiconductors and pharmaceuticals, have emerged as more significant components of the economy, employing thousands and pushing U.S. industry to greater heights.

The incorporation of advanced technologies into manufacturing processes and the rise of new technology-intensive industries drove these changes. These technologies are the products of innovative ideas from the public and private sector, emerged from an infrastructure of physical and human capital, and rest on knowledge accumulated from decades of public support for research and development (R&D).

Federal investments in computer numerically controlled machines, optics, robotics, microelectronics, lean production, lasers, the Internet, composite materials, and many other fields of basic research provided the seedbed for the current generation of

manufacturing process technologies. In turn, the development of next generation technologies depends on investments today in long-term R&D.

To sustain and accelerate the growth of manufacturing, the National Coalition for Advanced Manufacturing (NACFAM) concludes that resources must be committed now to ensure that the technical needs of the future are met. In particular, the research required for the development of the next generation of advanced manufacturing technologies demands a sustained national commitment. This paper summarizes the broad outlines for a national initiative in support of greater federal investment in basic manufacturing science and technology (BMS&T).[1]

- As a concept, basic manufacturing science and technology refers to the body of knowledge that is used in developing new, productivity-enhancing technologies for use in manufacturing. The proposal recommends an interdisciplinary research program focused on overcoming gaps in the existing knowledge base and provide the foundation for new scientific discoveries. This research will facilitate continued technical advancement across the breadth of the manufacturing enterprise.

For additional copies of this report contact NACFAM at: 202-429-2220

[1] In *Smart Prosperity: An Agenda for Enhancing Productivity Growth*, NACFAM outlines an argument for rebalancing the federal investment by increasing public expenditures in engineering and the physical sciences by $10 billion over 3years. This concept paper refines that vision further by outlining a specific proposal for manufacturing-related R&D.

Manufacturing's Contribution to the Nation's Economy

In 1995, the Commerce Department concluded that manufacturing is the most effective way for the United States to generate wealth in the 21st century economy. As an engine for growth, the Commerce Department put forth that, "manufacturing exercises the nation's productive capacities more extensively [than non-manufacturing industries], eliciting a broader array of inputs and providing special opportunities for productivity growth." This argument is supported by the following facts:

- Manufacturing accounts for 16% of U.S. GDP and employs approximately 14% of the nation's workers.
- From 1996 through 1999, GDP in manufacturing grew 5.1% annually, while the economy as a whole increased by 4.3% annually.
- Manufacturing accounted for 21% of the nation's GDP growth between 1996 and 1999.
- The manufacturing sector, together with the non-manufacturing industries that are directly linked to manufacturing, account for about 45% of GDP and 41% of national employment.
- Manufacturing employment today consists almost entirely of high-skill, technology-intensive jobs with wages well above the service sector.
- The vast majority, 72%, of U.S. exports are manufactured goods.
- U.S. productivity growth surged in the 1990s, driven by increasing manufacturing productivity. Between 1995-2000, labor productivity for the non-farm business sector increased at a rate of 3.1% a year.
- Manufacturing productivity has averaged a 4.3% average annual growth rate over the last 5 years (1995-2000), with durable goods manufacturing maintaining a blistering 6.8% average annual growth rate over the same period.Average annual growth in manufacturing value-added was 3.49% between 1996-1999, with manufacturing adding $1.8 trillion in value-added to the U.S. economy each year on average.
- Manufacturing leads all industry sectors with e-commerce shipments that accounted for 12% ($485 billion) of the total value of all manufacturing shipments.
- Manufacturers' drive the high-technology boom in the U.S. In 2000, industry performed 75% of the nation's R&D activities, while providing 66% of the funding. Industrial R&D expenditures jumped more than 8% per year on average between 1993-2000. Manufacturers account for more than 64% of all U.S. industrial R&D expenditures.

Source: NACFAM analysis of U.S. Government data.

Continued economic prosperity depends on the effective use of advanced technology to maintain and accelerate productivity growth. In particular, the introduction of advanced technologies into the extended manufacturing enterprise is necessary to produce the next-generation of goods faster, cheaper, cleaner and better. Unfortunately, the present direction of U.S. R&D policy may cause us to miss these opportunities through imbalance and underinvestment.

The time has come to chart a new course for federal basic research policy. In 1999, the House Science Committee completed a thoughtful and well-crafted review of U.S. research policy, concluding that it is time to update the nation's strategy.[2] Among other things, the Ehlers report recommends promoting economic growth through long-term funding commitments in basic and mission-orientated research, sustaining private-public partnerships, improving science and math education, and permanently extending the R&D tax credit.

This call to action coincided with the efforts of many others, who were also reevaluating the role of long-term research to the nation's future. In a series of studies on the sources of industrial competitiveness, the National Research Council (NRC) concludes decisively that robust government support for long-range research is absolutely critical to maintaining the research infrastructure and knowledge base on which industry draws.[3] Similarly, the industry-led Committee for Economic Development (CED) reached the same conclusion, noting that "adequate and sustained funding for basic research must be a high and consistent national priority."[4]

Unfortunately, the federal commitment to basic research in the areas most critical to manufacturing has declined, relative to the expansion of the economy. When public investment in long-term research is benchmarked against the performance of the economy as a whole, there is a clear indication of a looming investment shortfall. As the economy raced ahead in the 1990s, driven by the application of advanced technologies, public investment in the research infrastructure that produced those innovations consistently fell as a percentage of national economic activity. Since the early 1980s, the same trend is evident in federal support for the fields most directly related to productivity improvement in manufacturing (Figure 1).[5],[6]

---

[2] House Committee on Science, *Unlocking Our Future: Toward a New National Science Policy*, (September 24, 1999).

[3] Board on Science, Technology, and Economic Policy (National Research Council), *Securing America's Industrial Strength*, (National Academy Press: Washington, D.C., 1999): pg. 26, 47-49.

[4] Committee for Economic Development, *America's Basic Research: Prosperity Through Discovery*, (CED: Washington, D.C., 1998): pg., 39.

[5] As a share of national GDP, engineering basic and applied research by the federal government fell from 0.1% in 1982 to 0.068% in 1999. The physical sciences dropped from 0.077% to 0.052%. In constant dollars, government expenditures were flat during the period, indicating that the level of federal effort has not kept up with the expansion of the economy.

[6] The Bush Administration's FY 2002 R&D budget request gives little sign of a change in this pattern. Similar details are unavailable at the scientific discipline level, but the top-line accounts for the major R&D

The drop in federal support is most troubling because of the government's long-standing role as the principal supplier of funds for research activities of a long-term and high-risk nature. In fact, public investment in manufacturing-related R&D accounts for less than 5 percent of all federal R&D. Industrial expenditures on R&D continue to rise, but this investment focuses more on short-term development programs and less on longer-term applied and basic research.

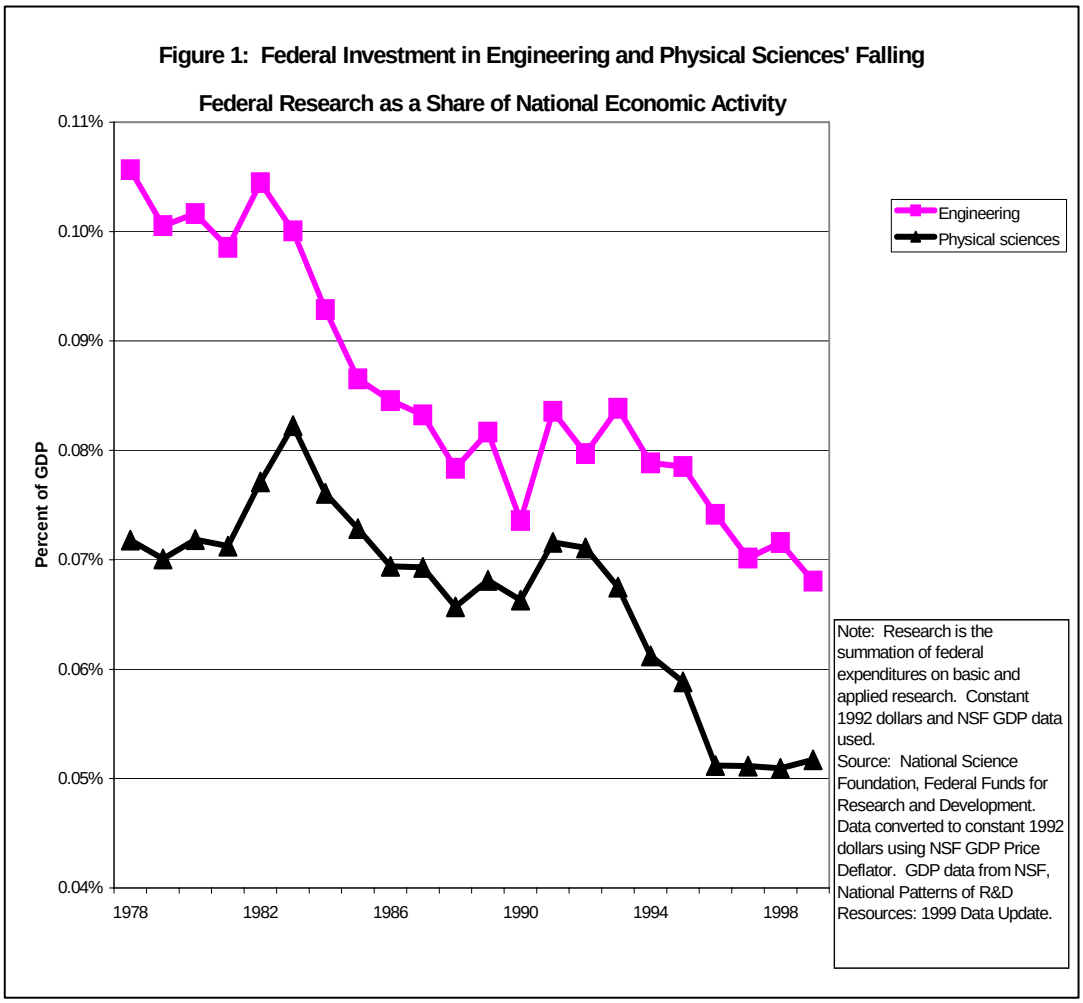
An important, but often overlooked, benefit of federal research funding is the education of young scientists and engineers. Federal support directly influences the ability of universities and colleges to support undergraduate and graduate students. These students are the future leaders of businesses and universities, the catalysts for continued technological innovation, and, consequently, a critical contribution to future economic prosperity.

As a consequence, there is a real danger of a national underinvestment in those areas most essential to future economic prosperity. Investing today in the research areas required for future manufacturing products and processes is the only way to make sure these capabilities will be available when the time comes to draw on them. This conclusion is shared by the National Research Council's Committee on Visionary Manufacturing Challenges that warned:

> "The recent pace of technological advances could lead to complacency and the belief that technology will be available "on demand." Today's advances, however, were the result of exploratory enabling research performed years ago. If manufacturing is to have the technical capabilities it needs in 2020, the research that will provide the scientific basis for these capabilities must be initiated now."[7]

agencies supporting engineering and physical science research are essentially flat. American Association for the Advancement of Science, *AAAS Report XXVI: R&D in FY 2002*, (AAAS: Washington, D.C., 2001).

[7] National Research Council, *Visionary Manufacturing Challenges for 2020* (1998), page ix.



A Renewed Federal Commitment

The critical shortfall in federal support for manufacturing-related R&D undercuts basic U.S. economic strengths, including the ability of the scientific and technical infrastructure to provide needed innovations, to educate and train new scientists and engineers, and to build the technical capacity required to meet challenging political, social, economic and national security needs. A concerted national effort, involving multiple federal agencies and active private sector engagement, on this specific area is required.

NACFAM calls on the leaders of the 107th Congress and the Bush Administration to consider investment in a research portfolio; the results of which will have profound positive consequences for governmental priorities and economic growth.

The 3-year, $5 billion program doubles the present commitment to manufacturing-related R&D. Presently, the federal government supports approximately $1.5 billion

to $2.1 billion in manufacturing research.[8] The research plan outlined here would (1) integrate existing efforts to accelerate the exchange of information and create opportunities for partnership; and (2) substantially expand the ability to support promising new areas, develop new techniques, and train additional students.

Seven Areas for Federal Research:

Seven preliminary investment areas were identified through an open, iterative process that solicited the views and insights of leading R&D experts.[9] The technical areas are notable for their inclusivity, none are targeted toward a specific industry, and their long-term, high-risk attributes, making them appropriate candidates for public support. The experts were asked to estimate a three-year budget required to begin the work outlined. Together, this research agenda would advance important national goals, such as:

- Accelerating the development of new industries;
- Reducing the cost of new military and space systems;
- Improving the efficiency and reliability of the national energy infrastructure; and reducing the harmful environmental effects of production processes.

The seven areas are:

1. Emerging or Breakthrough Process Technologies – ($1 billion over 3 years). This would catalyze ongoing efforts in meso-scale manufacturing, nanotechnology, biomedical manufacturing, bioprocessing, and new materials development. This research will facilitate the emergence of radical new products and fundamental shifts in how products are manufactured opening the door for whole new industries.
2. Intelligent Controls and Systems – ($500 million over 3 years). This research area would expand federal investments in microactuator technologies, perception and reasoning systems, and improve the integration and interface systems required for the effective use of these capabilities by people. Industries that succeed in effectively coupling machines with sensors, software, controls and computers - intelligent systems - promise to spark a revolution as profound as that of the computer.
3. Environmental Quality and Energy Efficiency – ($550 million over 3 years). This research area would support work in new materials development to reduce energy intensity in production and facilitate environmentally benign decomposition as well as expand research to improve production processes to

[8] NACFAM, *Federal Support for Manufacturing Science and Technology: An Analysis of the Federal R&D Budget*, (NACFAM: Washington, D.C., 2001).
[9] In developing the BMS&T proposal, NACFAM employed two groups of advisors. One group was asked to consider the long-term R&D needs of U.S. manufacturers. Based on that analysis, this group outlined the broad parameters of a research agenda. A second group offered insights into the best structure and organization for a federal research initiative. NACFAM, *Basic Manufacturing Science and Technology Initiative: Technical Focus Areas*, (NACFAM: Washington, D.C., 2000).

minimize resource-intensity and pollution. This research will enable 21st century manufacturers to not just to make things better and cheaper, but also make them in ways that minimize resource consumption and waste.

4. Pervasive Modeling – ($200 million over 3 years). Modeling and simulation, and the mathematical foundations on which they rest, are ever more crucial in manufacturing. By working with increasingly complex processes, manufacturers must make continuous and significant decisions under extreme uncertainty and risk. This research area would expand research in the theories and models that can be used to improve the soundness of those decisions, helping manufacturers reduce costs and improve quality.
5. Interoperability of Software Systems – ($500 million over 3 years). Imperfect interoperability of software and hardware systems is slowing the transformation of manufacturing brought about by advanced information technologies, costing the nation billions in inefficiency and redundancy. With greater understanding of self-integrating systems, human factors, and decision theory, advances in measurement and standards to facilitate hardware and software interoperability are possible. Devising answers to the interoperability problem will make major contributions to national productivity by enabling the efficient exchange of information – a factor that is increasingly common in the information-intense systems employed by manufacturers.
6. Knowledge Management and Learning Systems – ($1 billion over 3 years). Encompassing the tools and technology that support knowledge management and learning, this area would support work in the application of expert systems, autonomous agents, emergent systems, and other forms of applied intelligence to assist the conversion of data to knowledge. Enhanced knowledge management is essential to avoid being overwhelmed by the flood of information and data that is inherent in this age of information-intense manufacturing. This research will develop tools and techniques to transform these information flows into useable knowledge.
7. Web-based Design and Manufacturing: A Pilot Project – ($300 million over 3 years). The pilot project would generate a baseline understanding of structures and processes, devise an architecture design, devise tool-kits appropriate for small- and medium-sized manufacturers (SMEs), and pilot broad connectivity in the SME community. With rapid advances in information technology, this pilot project would provide manufacturers with the means to acquire information efficiently and adjust their production processes accordingly. The 3-year proposed expenditure for this research program is $5 billion.[10] The figure represents a substantial investment by the federal government to explore new areas of research and catalyze the training of the next generation of students. These proposed priorities build on existing federal priorities. As outlined, the technical focus areas would both integrate

[10] The expenditure estimates are the product of discussions among the technical subgroup of NACFAM's Advanced Manufacturing Research Study Group (AMRSG).

and complement existing research priorities.[11]

Figure 2: ***Federal Investments Make a Difference***

Manufacturing has rarely been a focused priority of the federal R&D portfolio, but support of generic technologies and research related to specific programs have resulted in a number of breakthroughs that have had enormous positive benefits for the nation. The four examples below illustrate how support for manufacturing-related R&D yields significant cost, quality, and capability benefits to both government and industry.

Clean rooms are critical to the development and production of advanced electronics, information technologies, pharmaceuticals, and medical devices. Dust, pollen, lint, and any of the millions of other things found floating in the air wreak havoc on the micro-scale manufacturing processes that are common to these industries. Sandia National Laboratories, a Department of Energy national security laboratory, confronted this same problem in designing systems for the nation's nuclear weapons arsenal. The technique they created dramatically reduced particle flow and became the industry standard, dramatically reducing failure rates, production costs, and enabling an entirely new generation of products.

Precision optics increase the accuracy of weapon systems, enhance surveillance, improve night vision capabilities, and drive advances in optical communications, integrated circuit fabrication, and a host of other commercial areas. An innovative partnership between the Department of Defense, research universities, and leading manufacturers produced a breakthrough technique that reduces the cost of producing precision optics by a factor of 10 with substantial improvement in quality. Application of this technique is underway in both defense and commercial production.

A consortium of aerospace firms and the Department of Defense worked together through the 1990s to devise a set of lean production concepts and practices for military aircraft and space programs. This work required the innovative use of computer models and simulations, development of knowledge management and learning systems, and introduction of new techniques, processes, and systems. The Lean Aerospace Initiative produced substantial savings, productivity gains, and quality improvements. Cost savings for the F-22 aircraft alone are in the tens of billions of dollars.

Automobiles and any other product comprised of metal rely on welds to join different pieces of metal. The quality of the weld affects the quality of the entire product. A bad weld could have catastrophic consequences. Argonne National Laboratory, a Department of Energy laboratory, developed an on-line laser weld monitoring device that can detect bad welds as they occur, allowing for immediate correction. Traditional monitoring techniques survey only a small sample of welds after the fact. Defects comprise the entire production run, producing tremendous waste and downtime. A pilot program current using the Argonne-developed device estimates system easily paid for itself within a month.

Source: NACFAM.

[11] NACFAM, *Basic Manufacturing Science and Technology Initiative: Technical Focus Areas*, (NACFAM: Washington, D.C., 2000).

A Multi-Agency Approach:

No single federal agency has responsibility for the R&D infrastructure as it relates to manufacturing, broadly defined, or the specified research areas, specifically. Indeed, a strength of the U.S. R&D system is the diversity of perspectives and opinions that influence direction and decision-making. Eight federal agencies have traditionally supported R&D work related to these topics, including:

- Department of Agriculture – Interested in sustaining the vitality and safety of production processes and techniques affecting the nation's supply of food.

- Department of Commerce – Interested in sustaining the health of the industrial technology infrastructure.

- Department of Defense – Interested in integrating technological advances from the commercial sector to maintain the technical and production capacity of the defense industrial base, enhancing capability with greater affordability, and promoting long-term research in areas relevant to defense missions.

- Department of Energy – Interested in manufacturing related to maintaining the nuclear stockpile, achieving energy efficiency and energy supply missions, and exploiting the capacities of the laboratory system for the public good.

- National Science Foundation – Interested in supporting the national capacity for innovation in engineering and the physical sciences to lead to creation of new wealth and quality of life.

- National Aeronautics and Space Administration – Interested in providing the foundation of expertise and advanced production facilities needed to meet the aeronautical and space transportation needs of the future.

- Environmental Protection Agency – Interested in research to control pollution and manage waste from industrial processes.

- Department of Transportation – Interested in research challenges related to advanced transportation and distribution systems, which are critical elements of the extended manufacturing enterprise.

Interagency Committee and Advisory Council:

Beyond recommending areas for investment, the proposed initiative also considers how the federal government might structure, organize, and coordinate this national research program. The BMS&T proposal recommends the creation of an Interagency Committee under the President, chaired by Department of Commerce, to provide top-level management and oversight of the initiative. This approach builds on successful efforts by recent information technology initiatives, such as, IT^2 and the High Performance Computing and Communications (HPCC), and the Global Climate Change Research Program to craft government-wide planning and information-

sharing efforts. It is also consistent with the use of the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) by the first Bush Administration and the National Science and Technology Council (NSTC) by the Clinton Administration to highlight national R&D priorities and coordinate activities.[12]

A four-year plan of action is envisioned. In the first year, the Committee will develop strategic plans, directives, and program guidance to facilitate the effective coordination of the technical agenda at the agency level. An advisory council comprised of leading private sector technical experts will be created to provide input and guidance in the development of the Initiative's technical agenda. Based on the technical agenda, the Committee will propose to the President a budget allocation for submission to and approval by the Congressional authorities responsible for funding the participating agencies. At the conclusion of the third year, the Committee will prepare and conduct a review and evaluation of the initiative and issue recommendations as to its continuation in a report to the Congress.

Such a structure would complement, not replace, agency decision making and implementation at a project level. The intent is to provide a means to coordinate operations and then evaluate the performance of the initiative, while providing sufficient discretion to the agencies to pursue the implementation strategies they see fit.

An Industry Role:

Private sector involvement is essential to success. In addition to the advisory council, partnerships and collaboration between government and industry are encouraged. Decisions on whether cooperative activities are appropriate should be made on a case-by-case basis, along with decisions as to the nature of the private sector match and distribution of intellectual property. Nevertheless, the Initiative recognizes the long-standing success of the government-industry partnership in manufacturing R&D.

Conclusion

Technology is the fuel of the prosperity "engine" of our economy. The application of advanced technologies, ranging from information and computing technologies to the use of new materials and process technologies, fueled the economic boom of the 1990s and are critical to sustaining prosperity in the future.[13] These technologies are the product of knowledge, competencies, and capabilities of the national research

[12] In fact, the last national manufacturing initiative was constructed and managed under the auspices of FCCSET in the early 1990s. Committee on Industry and Technology of the Federal Coordinating Council for Science, Engineering, and Technology, *Advanced Manufacturing Technology: The FY 1994 Federal Program in Manufacturing Science, Engineering, and Technology* (Washington, D.C.: National Science Foundation (93-221), August 1993).

[13] Alan Greenspan, "Technology and the Economy," Remarks before the Economic Club of New York, January 13, 2000 (http://www.bog.frb.fed.us/BoardDocs/Speeches/2000/200001132.htm); and Gregory Tassey, R&D Trends in the U.S. Economy: Strategies and Policy Implications, (NIST Planning Report 99-2, April 1999).

infrastructure. In particular, a new public commitment to expand public support for long-term research and technology is necessary to position that infrastructure to meet the science and technology challenges that will be faced by government and industry in the 21st century. The approach suggested by the Basic Manufacturing Science and Technology Initiative recognizes the significant contributions of long-term R&D to fulfilling critical government missions as well as the tremendous value it adds to the U.S. economy.

While industry has the central role in manufacturing R&D, an appropriate role exists for government as well. The federal role lies in supporting generic manufacturing technologies and those technologies that are directly applicable to the needs of government programs. The research agenda identified by the Initiative fits both those criteria. Action in these areas will greatly enhance the ability of federal agencies to meet their affordability, sustainability, and quality missions. At the same time, the Initiative calls for new activity in areas of wide application and diffuse benefits.

The long-term, high-risk, and diffuse applicability of the research activities in question make them unattractive to the industrial R&D community, which is focused increasingly on short-term, product development. Consequently, industry more and more depends on the broad foundation of research results and intellectual capacity arising from federal support for work at universities, federal laboratories, non-profit research institutes, and industrial laboratories.

The nation must focus attention on the research and technology areas most critical to the future of manufacturing enterprises. Steps must be taken now if the United States is to sustain productivity growth and continued economic prosperity.