ADVANCED MANUFACTURING

ABSTRACT

Current conditions suggest a resurgence of U.S. advanced manufacturing capabilities since 1990, but several potentially serious challenges remain, including financial pressures to reduce long-term research and development, barriers to technology deployment among smaller manufacturing firms, inadequacies in the current educational system, and declines or slower growth in productivity and wages. Because these problems detract from U.S. companies' ability to sustain global competitiveness, and because advanced industrial capabilities are an indispensable component of U.S. national wealth and power, government should assume an active role to achieve the following policies: Closer interaction between industry and educational institutions, strong support for government and industry partnerships that promote shared research and help develop new technologies, and economic initiatives that promote stable growth and capital investment in the manufacturing sector.

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INTRODUCTION

Although the U.S. economy is increasingly service-based, manufacturing continues to be a cornerstone of the nation's economy. Manufacturing accounts for 22 percent of the U.S. gross national product. Almost 21 million workers (17 percent of the U.S. work force) are directly employed in manufacturing. Additionally, every 100 manufacturing jobs support 60 additional jobs outside the manufacturing sector.

The manufacturing sector also conducts over 90 percent of U.S. nondefense research and development (R&D) and employs almost 75 percent of the nation's scientists and engineers. Manufacturing R&D provides the cutting edge for incorporating state-of-the-art technologies into new products, processes, and major improvements in productivity. As these innovations cycle through the economy, both the originating firms and society as a whole benefit from improved productivity, competitiveness, high employment, and a higher standard of living.

In addition to economic wealth, manufacturing industries are a key source of the materiels and technological capabilities needed to produce modern weapon systems and sustain sufficient military forces. Manufacturing is an important determinant of national power, both economic and military. Advanced manufacturing capabilities that require the interaction of highly trained humans, complex equipment, high technology, sophisticated management practices, and large organizations produce competitive world-class products and impact the ability of a nation to maintain security, project power, and influence world events.

This report focuses on the advanced aspects of modern manufacturing, its distinguishing features, and current industrial conditions. Industries are examined in a framework of three categories: (1) technology and equipment, (2) manufacturing processes, and (3) human and organizational aspects. Next, we address several challenges that potentially threaten the future of advanced manufacturing in the United States and the outlook for dealing successfully with those challenges. In the final section, we draw conclusions regarding government's appropriate role in addressing these challenges and recommend specific policy goals to improve the ability of U.S. advanced manufacturers to enhance national security in the future.

The diffusion of new technology shapes productivity through several channels: the purchase of technologically sophisticated machinery, equipment, and components; the acquisition of licenses or patents that enable one to use ideas developed elsewhere; or the simple borrowing of

ideas and expertise. But it is a firm's own innovative effort that allows the benefits of outside technology to be enjoyed.

Growth in Productivity

In advanced manufacturing, growth in productivity can be traced mainly to industries' own R&D expenditures—particularly in the machinery sector. Cincinnati Milacron, for example, has increased its capital spending significantly over the past three years in order to invest in modern equipment and systems. Through process redesign, the company is reducing machining and assembly operations, speeding up the production cycle, turning over inventory faster, and cutting rework and warranty costs.

Productivity growth in services and information technologies (e.g., transportation and communication services, finance, insurance, real estate, and business services), benefited considerably from the purchase of technologically sophisticated intermediate and investment goods from the manufacturing sector.

Yet the invention of new products and processes and their initial commercial exploitation generate fewer economy-wide benefits than their timely and widespread distribution. The economic performance of most manufacturing and service industries depends on adopting and using technological ideas and products developed elsewhere.

We believe that advanced manufacturing will continue to contribute its expertise to all industry sectors, thereby increasing their productivity, employment rates, and worker skills; and securing the future role of technology in shaping U.S. competitiveness at home and abroad.

The Evolution of Advanced Manufacturing

The United States, has emerged from the Cold War with two parallel industrial infrastructures—one for defense, the other for general commerce. Each sector relies on distinct technologies, production processes, and business practices. This legacy makes defense systems potentially unaffordable and encumbers our industrial competitiveness. The new world order demands a unified industrial base in which defense and commercial products share dual-use technology and are manufactured on next generation production processes that respond rapidly to changes in customer requirements and demand.

The continuing evolution of advanced manufacturing will create an open, flexible, and scaleable electronic infrastructure for manufacturing

in the 21st century. This infrastructure will provide standardized ways of accessing a wide variety of flexible production services over local area networks and the Internet. It is open because anyone will be able to offer services, and scaleable because it draws no distinction between services available on-site and those obtained from other divisions or outside companies. When fully developed, information technology will provide seamless access to flexible manufacturing services worldwide.

ADVANCED MANUFACTURING DEFINED

No single attribute or fixed set of elements inherently defines advanced manufacturing industries. Advanced manufacturing is better understood as an integrated system of the best human, organizational, and technological elements currently available. This report reviews a number of management techniques, business practices, organizational characteristics, technologies, processes, and human relations philosophies commonly found in advanced manufacturing organizations. Although each of these elements has important advantages, the essence of advanced manufacturing lies in how they are consolidated. Companies that effectively integrate these elements are the most successful creators, distributors, and supporters of world-class products.

Successful products take many forms, but all have the common characteristic of being the right product, in the right place, at the right time, competitively priced, and satisfying customers' quality expectations. Customer satisfaction, however, takes more than high quality today. Advanced manufacturers must also satisfy customers' demands for product differentiation. An industry's manufacturing processes and equipment must be flexible enough to build customer-driven product variations as efficiently as it produces cookie cutter copies. Customer demand is also highly changeable, and manufacturers must be agile enough to respond quickly to sudden shifts in customer demand to avoid debilitating losses of market share and large inventories of unprofitable product. A final distinguishing characteristic of world-class products is that they are created, used, and disposed of in ways that minimize damage to the environment. These product characteristics define advanced manufacturing more accurately than the mere list of techniques or technologies used to make the products. Thus, our definition of advanced manufacturing emphasizes both the integration of organizational elements and the value of its final products:

> Advanced manufacturing is an integrated combination of people, processes, machines, organizational structure, and management techniques that imbues products with globally competitive advantages that are measurable in terms of cost, quality, performance, customer satisfaction, and benign environmental impacts.

To achieve world-class results, a company does not necessarily employ every element of advanced manufacturing. Some companies may optimize certain elements to compensate for weaknesses in other areas. However, few firms succeed as advanced manufacturers unless they effectively integrate many of these elements. Customers can access markets anywhere in the world, and manufacturers must compete with each other on a global basis; that is, they must use manufacturing systems that are at least as effective as their competitors' systems. Instantaneous and ubiquitous global communications ensure that companies all over the world know which new technologies and business practices are most successful.

The key elements of advanced manufacturing evolve with time. The techniques and technologies that exemplify advanced manufacturing today may not be good enough to achieve world-class results tomorrow. Failure to keep pace with improved techniques and technologies guarantees a reduction in competitiveness. Thus, another characteristic of advanced manufacturing companies is the continuous search for, and implementation of, improved elements for their system.

Technologies and equipment associated with advanced manufacturing include machine tools, robotics, information technologies, and research and development. Advanced manufacturing processes address product development and production, quality, equipment maintenance, supplying manufacturers, and the environment. The organizational and human aspects of advanced manufacturing include the work force and organizational changes to ensure competitiveness.

CURRENT CONDITIONS

The manufacturing enterprise is undergoing significant changes in response to new market forces that are rendering mass production obsolete. These new forces include

- More intense global competition.
- Fragmentation of mass markets into niche markets.
- Greater cooperation among companies, to include competing firms.
- Increased expectations for customized products that do not sacrifice quality or reliability, and do contain costs.
- Greater social pressures that are shaping new ways that companies must conduct business.

To cope with these pressures, manufacturers have become leaner and more flexible. Compared with mass-production manufacturing, lean manufacturing develops new products using a fraction of the human effort, manufacturing space and inventory, investment tools, engineering hours, and real time. Flexible manufacturing processes allow them to adapt to changing conditions such as new technologies, customer preferences, regulatory constraints, monetary exchange rates, tariffs, and labor wages. Flexible, alert organizations adapt quickly, reducing the production cycle, and rapidly changing from product to product. The challenge for advanced manufacturing enterprises is to change quickly and economically. Doing so requires the appropriate application of systems, processes, and technologies to gain a competitive advantage.

Advanced Manufacturing Technologies and Equipment

Machine Tools. The machine tools industry is a critical part of the manufacturing enterprise. Advanced manufacturing relies on machine tools, not only for manufacturing consumer products, but for making the machinery of production. Machine tools shape, form, and cut metals, plastics, ceramics, and other material composites. They are often classified by functional category (e.g., drill press, punch, lathe) and by control device (manual, numerical control, and computer numeric-control). Computer numeric-controlled (CNC) machines use advanced software applications to reprogram automated movements easily and quickly. U.S. automotive and aerospace firms recently joined forces to facilitate their conversion to open, modular-architecture controls that make hardware replacement, upgrade, and interchange much easier.

The relatively small size of the machine tool industry in the United States does not reflect its significance to the nation's economic viability. The health of the industry often reflects the state of manufacturing. Accordingly, the United States lost its market share in the machine tool

industry when domestic production plummeted in the 1980s. This loss was exacerbated by improved foreign, particularly Japanese, machine tool products and services, and the high value of the dollar that hurt price competitiveness at home and abroad. Today, the U.S. share of the world's machine tool market is about 7 percent; Japan and Germany own the greatest market share. American machine tool manufacturers are generally small, family-owned firms with limited financial resources. Many were purchased by foreign firms during the domestic downturn of U.S. manufacturing during the 1980s.

Robotics. Robots execute specific functions in the manufacturing process (e.g., welding, lifting, and cutting). Robots typically replace and consolidate functions formerly done by humans, particularly repetitive or unsafe tasks, but also complex operations easily distorted by human error.

In the earlier stages of robotics development, some companies misapplied robots or overestimated their potential, resulting in low return on investment and high life-cycle costs. Most advanced manufacturers today conduct thorough cost analyses, identify training requirements, and integrate robots into their overall manufacturing systems. Over 72,000 robots are now at work in U.S. factories, and orders for new robots from U.S.-based companies have doubled since 1992, surpassing $1 billion.

Information Technologies. The role of information technologies in advanced manufacturing continues to grow. These technologies facilitate both materiel requirements planning (MRP I) and manufacturing resources planning (MRP II). State-of-the-art manufacturing execution systems (MES) are interactive, dynamic information systems that drive the manufacturing process from the point of order to delivery of the final product. Advances in simulations modeling support the design, virtual testing, and rapid prototyping of everything from automobile engines to aircraft, enhancing integration, and significantly cutting costs and approval-to-launch times.

Manufacturers continue to refine and exploit the vast potential of computer-assisted design (CAD) and manufacturing (CAM). These applications support rapid prototyping for design verification and preliminary testing, and the integration of design, production, distribution, marketing, and other functions. They also permit manufacturers to use secure electronic media to disseminate critical data

immediately within their companies and among their suppliers and overseas operations.

Research and Development. Six of the largest U.S. corporations collectively decreased their R&D by 30 percent between 1991 and 1994. Focusing on designing innovative products that offer a quick return on investment, U.S. firms have traditionally favored product-oriented R&D. Some leading-edge firms are investing more in process-oriented R&D. Firms are forming alliances with each other and with academic and non-profit researchers and the government to share R&D expenses. Government labs, for example, facing dwindling federal research funding, are collaborating with U.S. automakers on projects such as the Partnership for a New Generation of Vehicles (PNGV). A primary purpose of such initiatives is to link advanced technologies to manufacturing processes.

Advanced Manufacturing Processes

Product Development. Manufacturers are slashing the production cycle to reduce costs and enhance productivity. They apply integrated product teams, benchmark their competitors, and use sophisticated information technologies to help integrate processes to cut product development time and costs. Still, some major U.S. manufacturers lag behind their domestic and foreign competitors by a wide margin. Many U.S. manufacturers are world-class in design, but falter during production because they have not adequately integrated the design, engineering, and manufacturing process.

Production. Manufacturing in the United States is characterized by constant advances in production processes. One recent advance is the integration of personal computer-based human-machine interface applications and controls on a single, open-architecture platform. These systems enhance efficiencies by controlling inventories, tracking production, and documenting quality data.

Flexible manufacturing cells is a term used to refer to the integrated and automated machine tools and robots that produce high-quality, precision products around the clock. These cells can be programmed to support the production of various products by the same set of machine tools.

Quality. The Big Three automakers currently achieve about 120 defects per 100 vehicles, a vast improvement from the 1980s, when 750 defects per 100 vehicles was the norm. Quality control has shifted from the end of the production line to become an integral part of all aspects of product development. By incorporating quality measures throughout the manufacturing process, some U.S. automakers no longer have to hot-test engines before shipment. The International Organization for Standardization (ISO) oversees the quality certification of manufacturers around the world using standards such as the ISO 9000 series. ISO certification becomes critical to global competitiveness as more countries require certification as a condition for market access.

Maintaining Manufacturing Equipment. Manufacturers looking for every competitive edge are placing greater emphasis on maintaining their increasingly sophisticated equipment to minimize lost production time. Ease of maintenance has, in fact, become an important consideration in the design of manufacturing machinery. Equipment maintenance is carefully programmed into production scheduling and workers are more highly trained on maintenance procedures. The result is reduced downtime and higher-quality production.

Supplying Manufacturers. Cost pressures force manufacturers to minimize their parts inventories and outsource more production of parts and components. Since the purchase of parts and essential components (the supply chain) accounts for as much as 70 percent of the cost of many products, original equipment manufacturers (OEMs) are squeezing suppliers to cut costs, and some U.S. automakers require 5 percent reductions in parts costs each year. As a result, first-tier suppliers are outsourcing more engineering work and transferring cost pressures down to second- and third-tier suppliers. OEMs are developing partnerships with suppliers, helping them with productivity challenges, and sharing software technologies with them, to facilitate the communication of design specifications and production schedules. This communication facilitates timely parts delivery, minimizes costs associated with storage space and investment in parts, and supports flexible and agile manufacturing. OEMs are bringing suppliers into the earliest stages of product development to ensure that costs and specifications are integrated throughout the process.

Environmental Considerations. Environmental considerations have likewise assumed a greater role in manufacturing. Compliance

requirements affect productivity and influence where manufacturers locate their production. The ISO 14000 series of international environmental management standards has become a major factor in manufacturing operations because adherence is either expected or required, both domestically and internationally.

Organizational and Human Aspects of Advanced Manufacturing

Organizational Adaptations. Lean organizations are smaller and flatter, relying more heavily on empowered, self-directed teams and individuals to drive productivity and quality improvements. Firms are using teams and horizontal management models to integrate various manufacturing functions throughout product development and production. Automakers are achieving integration by having the chief engineer and plant manager co-chair product teams that include designers, suppliers, dealer representatives, and other key players. The result is much shorter cycle times, higher productivity, and greater responsiveness to market demands.

Collaborative trends between organizations are reflected in domestic and global alliances to share burdens, capitalize on strengths of respective partners, hedge against currency fluctuations, and comply with domestic content requirements of consumer nations.

The Work Force. U.S. labor costs and productivity are globally competitive, contributing to the influx of foreign transplant manufacturers in the United States. Rapid changes in the U.S. work force are characterized by declining labor union membership, greater use of lower-paid temporary workers, and the shift to, or concentration of, manufacturing plants in right-to-work regions. Union membership is currently at its lowest level in more than 50 years. Relationships between labor and management are increasingly cooperative and unions have been instrumental in achieving numerous productivity gains. However, remnants of an adversarial relationship persist, occasionally disrupting production and resulting in loss of market share that is difficult to recapture. Unions have hindered the efforts of some major U.S. manufacturers to outsource, forcing the use of higher cost in-house suppliers. Temporary employment has grown three times faster than employment as a whole over the past decade. Some manufacturers who have shifted from hourly to salaried work forces report that their employees are experiencing higher job satisfaction and lower absenteeism.

The ability of education to support advanced manufacturing in the United States varies widely by locality. Many manufacturers work with local schools and universities to develop required employee skills and improve worker quality. The degree to which manufacturers promote employee training is similarly varied. Many competitive manufacturers have embraced employee training, and the positive impacts on worker satisfaction and productivity are impressive.

The Globalization of Manufacturing

Global market forces are contributing to the increasingly "borderless" nature of the manufacturing enterprise. The national origin of products has less meaning once their parts are procured from multiple nations, to be assembled and manufactured in a different location, and finally customized for marketing in yet another locale. Flexible, agile manufacturers position various manufacturing functions to buffer the firm against changing labor costs and currency exchange rates, tariffs, regulations (such as local content requirements and environmental laws), and consumer needs. Some firms are avoiding large capital investments by outsourcing manufacturing processes such as product assembly to contractors who can quickly set up manufacturing facilities and produce quality products.

The higher-value aspects of advanced manufacturing are sought by developing nations such as China as a way to improve their standard of living and global stature. Developing nations often require manufacturers to establish higher-value manufacturing functions locally before granting them access to local markets. Although a proliferation of manufacturing has occurred throughout the world, labor-intensive and less technical functions are often performed in developing nations such as China. Manufacturers find it challenging, for example, to employ progressive labor techniques in China, since Chinese culture does not promote the teamwork that has been so vital to the success of Japanese manufacturers.

The manufacturing enterprise has declined in some nations, for example, Germany, as a result of labor, regulatory, and tariff conditions that are unfavorable for business. Once a major manufacturing power, Germany has moved much of its production to other countries, retaining only certain functions such as product development closer to home. Other nations, such as South Korea, are mounting aggressive campaigns to achieve world-class manufacturing capabilities.

Many Japanese manufacturers are now promoting what they call a "harmonious" approach to manufacturing. By balancing the human element with safety, the environment, and progressive business practices, they continue to promote a more comprehensive, holistic approach to manufacturing. Though challenged by an aging work force and fluctuating exchange rates, Japan has aggressively pursued the further globalization of its manufacturing prowess.

U.S. manufacturing capabilities remain fairly impressive across the full spectrum of advanced manufacturing. However, a shorter-term focus on the bottom line may erode America's manufacturing strength as fewer resources are dedicated to key functions such as R&D and employee training.

CHALLENGES

The overarching challenge for advanced manufacturing today is global competition. Like advanced manufacturing itself, the challenge of global competition is a composite of many elements that can vary from company to company and industry to industry. Thus, global competition not only presents a different face to different companies, it is also different when viewed from a national perspective. Whereas companies engage in global competition by struggling to sustain competitiveness against other companies, countries struggle to create internal environments that attract capital investment, often with many companies competing in the same industry. Ultimately, however, manufacturing success for companies or countries lies in their ability to integrate solutions to specific combinations of manufacturing challenges.

Advanced Manufacturing Technologies and Equipment

Research and Development. As noted earlier, short-term pressures for financial returns make it increasingly difficult for publicly owned companies to invest substantial sums in long-term R&D. Yet R&D remains a vital component of long-term competitiveness: it creates new products, processes, and technologies that often result in quantum gains in productivity. The challenge faced by many American companies is how to sustain adequate R&D budgets while simultaneously satisfying shareholders with high investment returns. Many companies are seeking

government partnerships or multicompany industrial alliances to pool R&D budgets and share the results.

A multitude of technical R&D challenges face the manufacturing community. These include telecommunications security and encryption, open architecture software for machine control, standards for the translation and transmission of electronic data, advanced materials research, and others. Developments in these areas will have major impacts on the global competitiveness of manufacturing enterprises.

Machine Tools. The U.S. machine tool industry supports a small number of large companies, such as Cincinnati Milacron, but the bulk of the industry is composed of small, family-owned businesses that assemble low-to-medium technology machine tools and manufacturing cells. While most of the large companies have the financial resources necessary to adopt new technologies, few of the smaller machine tool companies have sufficient risk capital to take on the investment and training costs associated with new technologies. For this reason, deploying new technologies and recapturing market share lost to overseas manufacturers is especially challenging for the majority of U.S. machine tool firms.

Advanced Manufacturing Processes

Product Development. Shorter product development cycles help manufacturers compete for market share and profits. First, the faster a company can develop a product, the more responsive that company will be to changing customer requirements and tastes. Second, rapid product development enables manufacturers to exploit new market opportunities. Third, shortening product development time reduces costs by using fewer engineering hours and less design overhead. The result is a price advantage over companies with longer product development cycles and the ability to profit from smaller production runs. Last, the cooperation that engineers, managers, and production workers need to achieve rapid product development demands a level of teamwork that also enhances product quality.

In the automobile industry, for example, where each day eliminated from the product development cycle saves over $1 million, manufacturers are taking steps to reduce product development time. Many of these manufacturers face the additional challenge of phasing out a large number of older CAD/CAM systems in favor of a single enhanced CAD/CAM system that can facilitate concurrent engineering,

supplier responsiveness, and faster product development cycles. For example, costly prototypes can be eliminated (or at least reduced) using the modeling and simulation capabilities built into new generation CAD/CAM systems. The challenge is the time and money it takes to convert a large organization over to the new methods. To be competitive with Chrysler, for example, Ford, needs to cut $1,000 from its product development costs. The Ford 2000 program is the company's answer. This program will cut development time by 30 to 40 percent. It includes concurrent engineering and a new CAD/CAM system that incorporates paper transmissions of data, fewer engineering steps, and a 50-percent reduction in prototypes.

Organizational and Human Aspects of Advanced Manufacturing

Work Force Education and Training. One of the most difficult challenges facing U.S. manufacturers is that many graduates of American secondary schools lack the basic skills in reading, math, and human relations needed to succeed in advanced manufacturing jobs. Companies often have to screen large numbers of resumes to find suitable personnel or conduct remedial training for the workers they hire. The challenge facing manufacturers is how to partner effectively with schools to prepare workers for manufacturing jobs.

Productivity. Improving productivity is a constant challenge for advanced manufacturers, who want to remain competitive in the global market. Productivity improvements originate from several sources. Research and development and process organization have already been mentioned, and the human work force is equally important. As the closest observers of the manufacturing process, workers are keenly aware of inefficiencies or areas that could be improved. The key challenge is to empower the work force to develop and implement its new ideas and methods. Incentives, such as awards, performance-based compensation, increased wages, and morale-building tactics, such as team work and worker access to decision makers, are important components in meeting this challenge. For example, the Saturn Corporation uses a system of risk/reward pay to encourage productivity improvements in its work teams.

OUTLOOK

U.S. advanced manufacturers are currently in a strong position, as many companies have adopted lean manufacturing processes and are slowly evolving toward flexibility and agility. These trends have certain implications for the Department of Defense (DoD). The trend toward leaner manufacturing builds our defense capabilities because it can more rapidly field new products and weapon systems during a national mobilization. However, the manufacturing technology for weapon systems may not always be adaptable to the equipment and methods used for consumer goods. A negative implication is the tendency for lean manufacturing enterprises to run at near capacity rates and with minimum inventory, suggesting little excess capacity or inventory available for surge situations.

The U.S. machine tools and capital goods industries are particularly vulnerable to economic downturns, as shown in the 1980s when Japanese tool makers took over a large portion of market share in this area. Although the 1990s have seen a resurgence in this industry few changes have occurred in the machine tool industry to improve the ability of small firms to survive the next downturn.

The outlook for R&D is somewhat more encouraging. Many industrial alliances and government partnerships are currently funded. Examples include the Partnership of Next Generation Vehicles and the National Institute for Standards and Technology's Advanced Manufacturing Technology program.

Educational institutions are receiving a great deal of scrutiny in the United States. However, it remains to be seen whether widespread reforms will be undertaken to improve the outlook for work force education. Current proposals for modest funding increases, national standards, and performance-based pay for teachers are too controversial and limited to assure an improved outlook.

GOVERNMENT GOALS AND ROLE

Although the role of government in manufacturing has varied over time, it is characterized by a wide range of activities and spans the entire spectrum of manufacturing from research and development to traditional manufacturing processes. In the United States, both industry and the

nation as a whole have common interests in promoting a world-class education system, technology, and economic stability.

The government plays an important role in securing an educated work force to support the growing and changing needs of manufacturing. To ensure continued viability in an increasingly competitive global manufacturing environment, industry requires workers with skills and knowledge in a range of academic, business, technological, and work place subjects. The government must promote closer interaction between industry and educational institutions that includes determining whether and how job skills can be required in school curriculums.

Government agencies have also provided grants to private industry to fund research on promising ideas. The nonprofit Manufacturing Technology Centers (MTCs) of the National Institute of Standards and Technology (NIST) help small- and medium-sized companies adopt state-of-the-art manufacturing technologies and management concepts. MTCs are being combined with several other NIST outreach programs to form the Manufacturing Extension Partnership (MEP) programs.

The degree to which government gets involved depends on many factors, but national security considerations have been a primary driver. When the country is embroiled in a national crisis or war, or when its leaders perceive other threats to national security, such as increasing foreign competition or development of new technology by a potential adversary, then government plays a larger role. Political considerations, such as what constituency is served when Congress supports a specific industry, or which congressional district will get jobs, also influence the level of support—as do philosophical differences among the various political parties and branches of government. Finally, the budget environment and the potential effect of government support for manufacturing on the budget deficit are significant factors in determining government's role.

The technology infrastructure of the United States is basically strong, but the complex set of interdependencies among industry, government, and academia on which this infrastructure relies is currently changing. Unless these partnerships are understood, uncontrolled arbitrary changes in the fabric of their relationships could lead to its unraveling with irreversible and undesirable consequences for the nation.

Dynamic changes have occurred during the past five years in both manufacturing and the political climate. Technology became a major issue in the 1992 presidential campaign. After the election, federal technology programs grew rapidly. The budget of the Commerce

Department's Advanced Technology Program (ATP) grew from $47 million in 1992 to over $400 million in 1995. The DoD received an appropriation of $500 million in 1994 to accelerate the application of defense technology to civilian needs through the Technology Reconversion Program (TRP). National labs were also given incentives to establish partnerships with industry. Even as this growth occurred, however, many in Congress sought to reduce or eliminate these programs—and the departments of Commerce and Energy—in an effort to reduce the size of the federal government.

As a general proposition, this report recommends that public policies concerning advanced manufacturing should be guided by a better understanding of the role of manufacturing in the economy and its relevance to the national interest. Those interests are closely interwoven: industry seeks a favorable climate for profitable investments, and the nation needs that investment to enjoy economic growth, security, and a high standard of living.

The government supports the manufacturing enterprise in the United States primarily by ensuring the nation's economic stability. The prudent application of fiscal and monetary policies that encourage low inflation, high savings, capital investment, and other benefits promotes the nation's advanced manufacturing enterprise and secures its defense.

CONCLUSION

The overall health of advanced manufacturing in the United States is very good. However, the nation cannot afford to rest on past successes, but must move toward greater innovation and risk taking to maintain its position in the global environment.

The joint involvement of industry, government, and academia is crucial to our success. Without it the United States will face increased competition from abroad—capable, perhaps, of displacing us in the global market place, leaving us with an industrial base incapable of responding in a time of crisis, and no mechanism for the sharing of ideas and technology that stimulate growth and produce a world-class economy.

Without doubt the 21st century will be a time of tremendous growth around the world. The United States must be prepared to influence and manage this growth, notwithstanding its demand for effort, cooperation, far-reaching thought, and sufficient funding. It is certainly within the nation's capacity to accomplish this task and continue its world leadership.

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