ADVANCED MANUFACTURING

ABSTRACT

Advanced manufacturing centers upon improving the performance of U.S. industry through the innovative application of technologies, processes and methods to product design and production. This broad movement has enabled the growth of the U.S. manufacturing sector in the face of increasing competition, and has emphasized the importance of manufacturing to the nation's prosperity and to the ability of the U.S. industrial base to provide for the nation's security. Innovations will continue to transform manufacturing in ways that will allow U.S. producers to compete effectively in the global marketplace amidst rapid technological change and other pressures. However, industry and government must work together to surmount challenges and unlock the full potential of U.S. manufacturing, continuously strengthening the nation's well-being in the new century.

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INTRODUCTION

A strong and prosperous America depends upon a vibrant and growing manufacturing sector that can renew and create national competitive advantages in the midst of rapid technological change and the globalization of markets, production and innovation. After encountering growing international competition in the 1970's and 1980's, U.S. manufacturers sought new and better ways to compete in world markets. As part of this ongoing transformation, the broad implementation of advanced manufacturing technologies, processes and methods fueled the resurgence of U.S. manufacturers, serving as an engine of U.S. global competitiveness and economic growth.

Today, manufacturing is a stable, substantial, and pervasive part of the U.S. economy, occurring in a wide spectrum of industries throughout the nation's economy. The U.S. manufacturing sector accounts for about 17% of the U.S. gross domestic product and includes some 377,776 manufacturing establishments with over 18.5 million employees[1]. In view of the economic importance of the manufacturing sector and its critical role in resourcing the nation's security needs, reinforcing the vitality of U.S. manufacturing is essential to ensuring the nation's well-being in an increasingly competitive world. This report examines the current state of advanced manufacturing in the U.S., assesses its key challenges and probable future, and considers key implications for national security and the overall role of government in this critical sector of the economy. It also provides recommendations aimed at advancing the competitiveness of the U.S. manufacturing sector and strengthening its role in the nation's prosperity and security. The report concludes with three essays on key aspects of advanced manufacturing.

DEFINITION

The U.S. Census Bureau defines manufacturing as *the mechanical, physical, or chemical transformation of materials and substances into new products.*[2] Building upon this traditional view of manufacturing, we define **advanced** manufacturing as the innovative application and blending of technology, work processes and management methods into the production activities of manufacturing enterprises in order to obtain benefits such as increased productivity, improved product quality and greater operational flexibility, yielding competitive advantages and better performance in world markets. Importantly, advanced manufacturing involves the innovative integration of new technology, production processes and management techniques with the workforce, organization, and culture of the enterprise to form a total system of enhanced production. Indeed, as addressed in this report, the advanced manufacturing movement, in tandem with the information technology revolution, is transcending the traditional parameters of mass production, giving rise to a new era in manufacturing in which manufacturers are increasing the speed and flexibility of production while improving product quality and customization.[3]

CURRENT CONDITIONS

Economic Impact

As a whole, the contribution of manufacturing to the U.S. economy has remained stable and substantial despite the rapid expansion of the service sector and the recent economic slowdown. Manufacturing has accounted for 16% to 17% of the nation's GDP over the last 10 years,[4] generating solid profits of 6% to 7% on sales.[5] A key trend is the growth in higher-technology, higher-value manufacturing. U.S. high-tech manufacturing industries -- aerospace, computers and office machinery, electronic-communication systems, and pharmaceuticals -- accounted for an estimated 14.7% of the total U.S. production of manufactured output in 1997, rising from 9.6% in 1980.[6] Importantly, this ongoing shift in production corresponds with the increasing deployment of advanced manufacturing technology, processes and methods.

In the international marketplace, the U.S. is experiencing a substantial trade deficit in lower-technology manufactured goods, indicating stiff international competition and reflecting competitive pressures to reduce labor costs by moving unskilled assembly work to low-wage countries. Conversely, the U.S., along with other more industrialized nations, are shifting to the production of higher-value, technology-intensive goods requiring advanced manufacturing processes, higher skilled workers, and greater technological resources.[7] Although the overall U.S. trade deficit reached a record high in 2000, exports of technology-intensive products continue to increase.[8] Overall, the U.S share of world exports increased more than any other country between 1990-1997,[9] with manufactured goods accounting for 62% of this flow.[10] The trade deficit in manufactured goods is largely attributed to the strength of the U.S. economic expansion relative to the slow or negative growth in many other countries.[11] This deficit is partially offset by an inflow of foreign capital, which has made the U.S. one of the premier investment locations in the world and greatly assisted U.S. growth in manufacturing and other sectors of the economy.[12] Overall, the growth in international trade reflects the global integration of markets and the associated increase in competition as well as the robust competitiveness of U.S. manufacturers, particularly in higher-technology, higher-value goods. Advanced manufacturing is enabling U.S. manufacturers to compete effectively in world markets, and continued access to those markets is vital to their future growth.[13]

Human Resources

Demographics. Significant changes in the industrial labor force over the last decade have imposed new challenges and issues for U.S. manufacturers. The rising average age of the manufacturing workforce, and its growing ethnic and cultural diversity is creating a new demographic landscape to which manufacturers must adjust their strategies and practices. In addition, the increasing rate of worker retirement, sustained low birth rates, and the near-full employment economy in recent years have served to reduce the labor supply available for manufacturing. Manufacturers are experiencing difficulties in retaining skilled labor, and in recruiting new employees with the education and skills necessary for advanced manufacturing. While immigration has served to increase the

overall labor supply, most newcomers to the U.S. do not possess the skill levels required by today's manufacturing companies.

Education and Training. The transition towards technology-intensive production processes and the adoption of advanced manufacturing methods requires a manufacturing workforce with higher levels of education, current technical skills, and the ability for greater decision-making in line with enterprise objectives. Workers at all levels of the organization must be knowledgeable about their products, customers, and production processes. As manufacturing becomes more complex and more technology driven, education is increasingly important. Yet, a 1997 survey of 4,500 manufacturers identified shortfalls in basic math, writing, and comprehension skills, as well as other more basic job skills.[14] Studies have also shown a direct relationship between lack of basic job skills and employee disciplinary problems such as tardiness, absenteeism, and pilferage.[15] Accordingly, the lack of skilled labor is a significant barrier to manufacturing modernization and improving production performance. As the shortfalls increase and new skills are required, education has become a matter of increasing public debate. In recognizing that a world-class workforce is essential to achieving competitive advantages in world markets, manufacturers are investing in training programs and partnerships with local high schools and vocational training centers to recruit and develop a higher-skilled and more capable workforce.

Innovation

Technology: Over the last decade, enterprises throughout the U.S. manufacturing sector have successfully implemented an array of technologies as the centerpiece of efforts to gain advantages in increasingly competitive world markets. The innovative and broad application of technology in manufacturing operations has driven the sector's substantial gains in productivity and has made possible increases in product quality, profitability, production flexibility and market share. These positive increases have been the result of technology-enabled reductions in inventory, setup time, time to market, material consumption and rejection rate.

The U.S. leads the world in R&D spending with U.S. industry accounting for two-thirds of the nation's annual R&D investment ($150 billion in 1999).[16] The strong commitment of U.S. industry to the generation and adoption of new product and production technologies is a key component of U.S. manufacturing competitiveness. Overall, the nation's R&D investment has spawned a wealth of technologies that have served to advanced the state of manufacturing, including high-speed, computer-controlled machinery, fully integrated computer networking systems, and computer modeling and simulation for the design and testing of new products and production processes. Smaller companies, however, have not been as aggressive in incorporating new, state-of-the market technologies due to cost and risk factors. Among small manufacturers, utilization of computer-based technologies (e.g., Computer Aided Design/Computer Aided Engineering (CAD/CAE), and Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) systems) are responsible for the greatest gains in productivity and competitiveness.[17] For both large and small companies, however, fully computerized integration in manufacturing (CIM) is rare. The primary configuration is still stand-alone machines or "islands of automation". Use of shared databases will increase significantly

over the next three years but full integration will be limited. [18] Advances in simulation and other technologies have made concurrent engineering (CE), possible and make collaboration between companies easier. However, estimates show that only 10% of manufacturers practice CE and even this group is far from realizing the potential that the future holds.

Processes. In addition to technology, U.S. manufacturing companies are adopting organizational approaches and management processes to streamline and improve production performance. Organizational structures are becoming flatter and more functionally oriented, [19] and manufacturers are employing the Internet and associated information technologies to better integrate supply chains and form extended enterprises that blur traditional organizational boundaries. In addition, U.S. industries are striving to improve product quality and achieve other benefits through more efficient and effective manufacturing processes and methodologies that add to their competitive edge. U.S. manufacturers, for example, are increasingly incorporating international quality standards as set forth in the ISO 9000 series. These standards require design and production processes and methods that provide a basis for systematic, process-base management, continual improvement, fact-based decision making, and enhanced customer/supplier relationships. Many other quality methodologies exist; some focus on inspection, others focus on process control, and some are a combination of both.

In tandem with the focus on process improvement and quality management, industry has benchmarked enterprises in the U.S. and abroad that have demonstrated highly effective and efficient manufacturing processes. Over the last decade, three concepts have gained widespread acceptance as part of efforts to improve the performance of manufacturing enterprises: lean manufacturing, agile manufacturing and flexible manufacturing.

Today, lean manufacturing processes are utilized broadly to maximize efficiency in manufacturing operations. Efficiency drives down cost, enabling lower prices for the customer and greater profit margins for the producer. For example, manufacturers are commonly employing just-in-time ordering and delivery processes to reduce inventory costs and unnecessary production. Lean manufacturing, which is particularly widespread in the automotive industry, is gaining acceptance across the manufacturing sectors in conjunction with other leading manufacturing concepts, such as agile manufacturing. This concept centers upon the ability of a manufacturer to rapidly respond at minimum cost to changes in customer needs and market demand by utilizing the same production line to manufacture different products. Such an adaptive process allows manufacturers to maximize efficiency while effectively meeting the growing demand for customized products and more rapidly responding to shifts in market demand. Lastly, flexible manufacturing involves the systematic integration of multiple production cells or stages to form a single, adaptable production system. Such flexible systems employ high-speed, high-precision, computerized machinery and tooling that can perform a variety of machining operations to produce different parts and products while reducing production time and inventory stocks. Manufacturers seek to incorporate such flexibility into their production processes in order to achieve competitive benefits while optimizing capital investments in new production systems.

Contribution to National Security Strategy

In an era of rapid technological change and growing global competition, advanced manufacturing is an increasingly important means of sustaining and further enhancing U.S. security, prosperity and quality of life. Innovations in manufacturing generate competitive advantages that enable economic growth and provide for a robust, viable industrial base for resourcing the needs of national security. For example, the innovative application of information technology to production processes and manufacturing supply chains has allowed the U.S. to generate increasing gains in manufacturing productivity. As a result, the U.S. is able to draw upon a strong and diverse range of industries to develop and field the world's most advanced defense capabilities.

The resurgence and growth of U.S. manufacturing over the last 15 years has occurred in parallel with the increasing commercialization and globalization of the defense-related industrial base. The post-Cold War decline in defense spending caused firms to perish and merge within the defense sector, or to shift towards commercial markets worldwide offering higher growth and returns in order to reduce reliance upon defense sales. However, despite reform efforts, defense acquisition policies continue to impair the nation's ability to secure innovative, market-driven manufacturers as defense suppliers. As a result, the consolidated defense sector is at risk of becoming isolated from the commercial innovations and suppliers that are needed to best fulfill national security requirements. This risk is compounded by the decline in defense R&D since the end of the Cold War, reinforcing the defense sector's increasing reliance upon market-driven R&D and technological innovation. Nonetheless, while the strategic transition of the defense industry and related suppliers has introduced new complexities, the overall U.S. industrial base – strengthened by advanced manufacturing initiatives like lean, flexible and agile manufacturing – remains a robust and vital resource for meeting critical defense needs.[20]

CHALLENGES

To compete in the world marketplace and meet our national security needs, the U.S. manufacturing industry must respond to a number of challenges. The market environment itself is challenging – made so by the increasing effects of globalization and the accelerating rate of technological change and diffusion. Today, global ties – through goods and services trade, capital flows, and integrated production relationships – are generally broader and deeper than ever before.[21] Technological improvements in transportation, communications, information technology, and production have reduced the costs of doing business internationally, thus lowering significant barriers to trade and investment.[22] The globalization of markets has brought heightened competitive pressures to fulfill rising customer expectations throughout the world.

Accordingly, U.S. manufacturers must strive continually to generate and sustain competitive advantages in the global marketplace. Manufacturers must lower production costs, reduce environmental impacts, increase customer service, and more effectively coordinate demand, supply, production and distribution.[23] In doing so, it is necessary to maintain a rapid pace of innovation and leverage available technology to maximize productivity and achieve true product differentiation – in terms of quality, customization

and customer service. Thus, ongoing investment in focused R&D and the innovative application of resulting technologies in product design, production processes and tooling is essential to the future viability of U.S. manufacturers.

Specific challenges facing the U.S. manufacturing sector include the following: fostering advanced technology and innovation; improving the agility and flexibility of manufacturing processes; integrating information technology and knowledge management practices; increasing environmental compatibility and efficiency; maintaining a competitive workforce; accessing and expanding world markets, and sustaining a viable industrial base to meet our national security requirements. Each of these areas interact and contribute to the national goals of advancing the nation's prosperity, security and quality of life. The challenge areas of fostering innovation, environmental-friendly production, and educating the workforce are addressed in essays at the end of the report.

Successfully addressing the above challenges will allow manufacturers to achieve more rapid innovation, higher product quality, quicker time to market and shorter product cycles, reduced fixed capital and production costs, improved utilization of resources (less waste), and fewer harmful environmental impacts. Continued investment in R&D and process improvements is a necessary foundation for realizing these benefits for industry and society. The industrial workforce must also advance in tandem with technological change – this will require renewed efforts in the education and training of workers for increasingly more technical and demanding roles in technology-intensive manufacturing. In addition, unfettered access to world markets is necessary to foster the continued growth of the U.S. manufacturing sector that is fundamental to U.S. prosperity and security. Such growth requires that U.S. manufacturers are able to freely enter new and expanding markets in order to employ and further sharpen competitive advantages stemming from advanced manufacturing. In a period of reduced defense acquisition spending, the nation must explore and find ways to strengthen the defense industrial base while minimizing the burden to the taxpayer and leveraging the innovations competitively spawned by commercial industries.

In considering these challenges, it is important to do so in light of U.S. national interests and security strategy. The nation's future prosperity depends on the ability of U.S. manufacturing industries to compete effectively in the global economy. The accelerating pace of technological innovation and the global diffusion of technology and advanced manufacturing means that unless the U.S. manufacturing sector continually renews and creates competitive advantages in world markets, the nation is at risk of diminishing its future well-being. This presents the U.S. manufacturing sector and the nation with the overarching challenge of guarding against complacency. While overall the U.S. is a world leader in advanced manufacturing, the nation's competitive position in the global economy is not assured, and is contingent upon surmounting the challenges that limit the potential of U.S. manufacturers. To meet these challenges, industry and government must work together to maintain and foster the conditions for the continued competitiveness and viability of a robust U.S. manufacturing sector.

OUTLOOK

Economic

As a result of the unprecedented expansion of the U.S. economy, increasing industry investment in R&D, and the growing implementation of advanced manufacturing innovations and practices, the U.S. manufacturing sector is strongly positioned for future growth in the global marketplace. To maintain and further advance the nation's competitive advantages, it will be necessary to better focus national policies and efforts on supporting R&D to foster technological innovation in manufacturing, improving the education of the industrial workforce; and opening and expanding markets for U.S. producers. Improving the competitiveness of U.S. manufacturers amidst growing international competition will continue to rise in importance to the nation's overall well-being in the new century.

The future climate for industry investment in advanced manufacturing has become uncertain due to the recent slowdown of the U.S. economy. Long-term investments are less likely, particularly in small manufacturers which account for the largest share of the overall manufacturing sector. Investment in advanced manufacturing technologies will likely remain concentrated in large companies. In addition, manufacturers in the defense sector have a unique challenge. Of the five top defense contractors, two have BB bond ratings (10.3%), two have BBB bond ratings (8.13%), and one has an A bond rating (7.72%).[24] In all five cases, the cost to borrow exceeds the rate of return on investment, making continued capital investment unattractive, and undermining the ability of the leading defense firms, as well as other defense-related suppliers, to attract the capital necessary for manufacturing modernization.[25]

Lowering cost while improving product quality is the operational mantra for manufacturers seeking to compete effectively in world markets. Industry investment in R&D and the implementation of manufacturing innovations will continue to provide a vital means of attaining such competitive advantages and sustaining the overall productivity growth of the manufacturing sector.[26] Accordingly, industry is expected to continue its rising investment in R&D and the incorporation of technology into production activities. The bulk of this investment, however, will be focused on the development and application of product and manufacturing technologies required to meet near-term competitive pressures and market demands. Industry tends to under-invest in longer-term, high-risk technology research which is an essential precursor to the generation of future technological innovations. To fill this gap in market-driven, industry R&D, it will be necessary for the federal government to sponsor and stimulate investment in high-potential technology research areas in order to enable the emergence of new technologies that can contribute to industrial competitiveness and growth over the long-run.[27]

In addition, the steady integration of world markets, and other dimensions of globalization, will continue to shape the strategic environment for U.S. manufacturers. Multinational organizations and international agreements, such as the World Trade Organization and the North American Free Trade Association, will become increasingly instrumental in fostering open markets and free trade, and effective U.S. engagement in international forums affecting the global marketplace will be essential to advancing the

growth of the manufacturing sector and the nation's prosperity. Within this context, recurring trade issues, such as those concerning intellectual property protection, export control, and economic sanctions, will continue to influence national policy-making and the course of advanced manufacturing.

Human Resources

U.S. manufacturers will continue to emphasize the importance of science and mathematics for future employees. A well educated, technically skilled workforce that can fully exploit advanced manufacturing technologies and processes is essential to maintaining U.S. industrial competitiveness in world markets. Manufacturing modernization and stiff competition in dynamic markets will require workers who can stay abreast of new concepts, skills and technologies through team communication and life-long learning in order to fulfill emerging work demands. According to Bureau of Labor, 40% of the total new jobs between now and 2008 will require the equivalent of at least an associate degree,[28] reflecting the rising level of skills and knowledge that manufacturing workforce will need to perform effectively. The aging workforce and other demographic trends will continue to affect the growth and competitiveness of manufacturers, who will face increasing difficulty in recruiting an adequate supply of sufficiently skilled entry-level workers to replace the retiring workforce. In order to stay competitive, the U.S. manufacturing sector will continue to invest in workforce development through in-house training and private/public partnerships with local high schools, vocational/technical schools and other educational institutions. Additional government reform and investment in the nation's education and training systems will also be necessary to attain both the quality and quantity of workers needed for the higher value, higher technology-intensive industries of the future.

Technology

The future of advanced manufacturing technology looks bright. U.S. manufacturers will continue to emphasize the application of information technologies over improvements in equipment or physical manufacturing processes. These investment priorities reflect the degree to which advanced manufacturers have adopted e-business models and the effort they need to make to establish the information technology infrastructure and processes that are required to stay competitive. New software technologies will accelerate the design process and enable process-knowledge sharing throughout a company. This technology will include the human-machine interface necessary to enable people to more easily set new products; input and retrieve information verbally or graphically; and identify product characteristics, functional uses, limitations and marketability.

Emerging technologies such as biotechnology, materials technology, micro-electro-mechanical systems (MEMS), and nanotechnology promise to further revolutionize manufacturing by enabling design and production at the molecular or lower level. Such new products and manufacturing processes will make possible characteristics of strength, durability, and maintainability previously unseen in the history of manufacturing. Future

products will incorporate multifunctional materials with incredible life spans and produce them with less waste and environmentally harmful effects.

Computerized integrated manufacturing (CIM) will come of age as Manufacturing Resource Planning (MRP) and Enterprise Resource Planning (ERP) continue to expand their functionality using web-based capabilities to link together customers, producers, and suppliers. Focus will shift from within the enterprise to the entire market, with business-to-business (B2B) e-commerce becoming a major growth area. These reengineered enterprises will likely feature "lean thinking", flexibility, and agility in their management, engineering, and production processes. Computer modeling and simulation will become more prevalent as concurrent engineering continues to rapidly optimize designs and production processes across the entire product life cycle.[29] Instead of inflexible, vertically integrated manufacturing facilities, the vision of the future is the virtual manufacturing enterprise in which leading firms rely upon strategic partnerships for R&D and production in order to concentrate on selected core capabilities, such as product design, production planning and manufacturing technology. This will enhance overall agility and competitiveness in dynamic markets.[30] Suppliers will share in the design responsibility for the system and be involved early on, as the functional requirements flow down from the system performance requirements. This will allow for more even distribution of the risk and cost, while simultaneously resulting in increased flexibility and profitability. Overall, the transformation of production underway across the U.S. industrial base will enable U.S. manufacturers to maintain their role as a key component of U.S. economic competitiveness and growth.

Implications for National Security

The emerging realities of the twenty-first century will significantly influence defense manufacturing and its role in national security. Considerations cited by the National Research Council's *Committee on Defense Manufacturing in 2010 and Beyond* include the new and changing nature of threats to U.S. national interests and security; declining and constrained defense spending; consolidation of industry within the defense sector; the increasing rate of technological advancement throughout the world; and requirements for environmentally compatible manufacturing. The study identified six key defense-manufacturing capabilities for the future: composites processing and repair; electronic processes; information technology systems; weapons system sustainment; modeling and simulation; and improved production processes.[31] The realization of these capabilities rests heavily upon improvements and innovations in manufacturing that are applicable to both defense and industrial purposes, thus advanced manufacturing across the U.S. industrial base will remain of vital importance to national security and U.S. economic competitiveness.

GOVERNMENT GOALS AND ROLES

Goals

U.S. security, prosperity and quality of life depends upon the competitiveness of U.S. manufacturers and a robust industrial base capable of fulfilling critical defense needs. Accordingly, the U.S. should continue trade policies that provide U.S. manufacturers

with fair access to current and emerging world markets, and allow for the acquisition of materials and products critical to U.S. industry and the nation's security. Concurrent with policies for free and open trade, the U.S. should continue to promote the international enforcement of intellectual property rights and the control of technology exports in order to protect U.S. technological advantages in manufacturing. Also, U.S. industry and government must act in concert to protect advanced manufacturing facilities essential to defense production as a key element of the nation's critical infrastructure. In addition, given the globalization, commercialization and consolidation trends within the defense sector, the federal government should closely monitor the capability of key defense-related suppliers to support defense requirements, and work to ensure that alternatives to single-source suppliers are available. Similarly, as the defense sector increasingly outsources critical components of larger systems, the U.S. must take steps to guarantee access to global sources of supply and undertake strategies to provide for surge capabilities in key production areas in the event of national need.

Roles

The federal government has and should continue to perform a vital role in promoting advanced manufacturing through policies and programs undertaken in concert with industry to accomplish the goals outlined above. To this end, recommendations are outlined in the following areas.

Industrial Base Planning. The federal government must possess the capability to assess the status, capability, and capacity of the nation's manufacturing industry to meet defense needs. In the past, the DOD performed this function pursuant to Section 2505 of Title 10, United States Code.[32] However, largely due to a lack of funding, the military agencies have scaled back their capability to properly conduct industrial and technological capability assessments. While the DOD's past assessments focused on the industrial base's ability to support specific defense needs, a full assessment of the defense-related industrial base is required in order to better understand industrial capabilities and vulnerabilities affecting national security. In doing so, the U.S. should capture assessment data in a comprehensive information management system that can provide national policy-makers with timely and reliable information on industrial capabilities and defense production issues pertinent to national security.

Trade and Market Access. The government should use the full range of tools at its disposal to ensure the global competitiveness of our manufacturing industries. The health of the nation's industrial sector depends upon the successful negotiation of multi-national agreements to foster free trade and open markets. Accordingly, federal agencies (e.g. the Departments of Defense, State and Commerce) and Congress should work together closely in order to obtain favorable agreements and assure U.S. access to markets, suppliers and resources worldwide. In addition, the U.S. should promote strict compliance with international agreements for the enforcement of intellectual property rights that provide legal protection for technological innovations propelling the advancement of U.S. manufacturing.

Fostering Technological Innovation. In conjunction with promoting free and open competition in world markets – the primary catalyst for industrial R&D and innovation – the U.S. should strengthen efforts to sponsor and facilitate the generation, commercialization and adoption of advanced manufacturing processes and technologies

throughout the manufacturing sector in order to further boost U.S. industrial competitiveness. As part of these efforts, the U.S. government should seek to further stimulate broad and long-term industry investment in technology research and development by making the R&D tax credit permanent and enhancing its use by industry research consortia. The government should also endeavor to expand the participation of U.S. producers in the ongoing technological transformation of manufacturing by augmenting federal R&D programs, such as the federal-wide Small Business Innovative Research program, to focus on advancement manufacturing technology. In addition, given the high risks and costs associated with long-term technology research, the federal government should fund and mobilize R&D investment in high-potential research areas through private/public partnership programs, such as the National Nanotechnology Initiative and the Technology Reinvestment Plan, in order to provide the foundation for future manufacturing innovations. Lastly, the U.S. should strengthen technology extension and commercialization programs at the federal and state levels to facilitate the transfer, advancement and implementation of manufacturing technologies for both defense and industrial purposes. This would serve to better leverage the nation's global leadership in R&D and work to bridge the growing technology gap between the defense sector and commercial manufacturing industries.

Maintenance of the Defense Industrial Base. U.S. defense manufacturers are increasingly outsourcing production while retaining design and system integration functions. Decision-makers need reliable information on the industrial base available for resourcing defense requirements in order to make informed decisions and policies regarding the amount and mix of industrial capability that is necessary to maintain domestically. It is essential that the domestic industrial base retain the capability to produce certain critical and sensitive products for defense purposes. As the defense sector continues to consolidate, the federal government also must determine where to operate Government Owned Government Operated (GOGO) or Government Owned Contractor Operated (GOCO) facilities, and where to subsidize commercial production facilities.

Acquisition Reform. Current government acquisition practices neither encourage defense suppliers to adopt advanced manufacturing technologies, tooling and processes, nor provide incentives for efficiency. The federal government should reform its acquisition practices in order to enable manufacturers to recoup costs associated with R&D and implementation of advanced manufacturing techniques.[33] We also need to make the acquisition timeline match commercial production timelines more closely, and cut the amount of oversight and bureaucracy involved in government contracting. These efforts will help make defense manufacturing self-sufficient and attractive to commercial industry, ensuring our continued ability to lead the world in defense production and manufacturing technology.

Human Resources**.** The U.S. government should work with the manufacturing and educational sectors to foster a renewed national focus on the challenge of maintaining a world-class industrial workforce that can fulfill rising technical demands and further realize the potential of advanced manufacturing. Industry and education leaders must work collaboratively to ensure that vocational and technical education programs contribute to the development of a workforce that possesses the knowledge and skills necessary to optimize the competitive advantages enabled by innovations in

manufacturing. In tandem with industry and education and training organizations, the federal government should provide financial incentives and support to U.S. students and workers studying mathematics, sciences, engineering and technical trades to ensure that the nation produces a robust supply of increasingly qualified labor that keeps pace with manufacturing innovations – a key requirement for the future growth of the manufacturing sector. Lastly, government at the federal and state levels should increase efforts with manufacturers to create and implement on-the-job training programs that address pressing skill and knowledge gaps hampering the adoption of advanced manufacturing technologies, processes and tooling.

CONCLUSION

Advanced manufacturing is the backbone of American industry, pervasive in virtually every sector. Manufacturing has held a stable and robust percentage of the U.S. economy for many years and will continue to do so. Advanced manufacturing technologies (AMT) have led to the increases in productivity essential to U.S. economic growth and competitive advantage. AMT also provides a mechanism to meet the nation's changing defense needs and technological weapon system requirements. Our share of the global manufacturing market will continue to grow as we maintain the cutting edge of technology in our most advanced products.

The driving force behind the growth of advanced manufacturing is the development and implementation of advanced technologies and processes. While the level of investment in these innovations varies across manufacturing companies, the overall increase in productivity has been significant. These advanced technologies have driven changes in production levels, efficiency, and workforce requirements. To continue to maintain competitive advantage in the growing global market, industry and government must work together to invest in research and development. While the focus of industry is relatively short term, and emphasizes the development side of R&D, government support of advanced research in the universities and labs around the country is critical to continuing advancement.

To meet the challenges of this technological explosion, industry has found that it must work closely with educational and training institutes to grow the next generation of manufacturing workers. The current shortage of skilled workers is the biggest barrier to the continued integration of advanced manufacturing technologies and processes. Through a combination of in-house training programs and cooperation with high school and vocational education facilities, advanced manufacturing companies are meeting this challenge.

Advanced manufacturing impacts U.S. national security economically, technically, and even diplomatically, as the government works to open and maintain overseas markets for American goods. Our military forces depend heavily on a waning defense industrial base and advanced program research efforts, which the government monitors, controls and supports. Advanced manufacturing technologies and processes will aid this industrial base by providing faster, more agile, and increasingly flexible weapon system development and production capabilities, but without significant changes to Department of Defense acquisition and budgeting procedures, the U.S. military may lose its

competitive edge. We must ensure government procurement processes keep pace with manufacturing capabilities.

The future of advanced manufacturing depends on continued investment in cutting-edge research and development, expanding global markets, and an educated workforce. Private industry and government must partner when and wherever possible to leverage all their relative capabilities to ensure that U.S. manufacturing will continue making the successful contributions so important to our national security.

INDIVIDUAL ESSAYS

Fostering Technological Innovation in U.S. Manufacturing Enterprises

Mr. Jonathan Root and Mr. Arthur Hommel

Technological innovation has had a primary role in both shaping and enabling the resurgence and transformation of U.S. manufacturers since the early 1980s. Most notably, the "arsenal of new technologies"[34] implemented by manufacturers during this period is widely credited with the remarkable growth in manufacturing productivity, and thus contributing substantially to the unprecedented expansion of the U.S. economy over the last decade. Innovation in manufacturing, if sustained, can continue to serve as a vital source of productivity growth and other competitive advantages for U.S. enterprises that will yield future dividends for the vitality of the U.S. industrial base and the nation's overall prosperity and security

Accordingly, industry and government leaders together face the challenge of fostering technological innovation across the spectrum of U.S. manufacturing industries at a pace sufficient to sustain and create competitive advantages in the global economy. This challenge is made more pressing by the criticality of pro-actively exploiting new technologies in an era marked by accelerating technological change, the quickening diffusion of technological innovations, and stiff competition on a global scale. In considering the innovation challenge, this essay (1) examines technological innovation in the context of manufacturing enterprises, (2) reviews their sources of innovation, and (3) identifies key considerations and practices in leading innovation. The essay concludes with recommendations for promoting sustained technological innovation in the overall U.S. manufacturing sector.

Technological Innovation and Manufacturing

Technological innovation is defined for industrial purposes as the incorporation of technology into the production activities of an enterprise in order to obtain benefits that translate into marketplace advantages and economic gains for the enterprise. As such, it is a difficult, multi-disciplinary process that involves the generation and/or acquisition of applied scientific or technical knowledge (i.e., technology) and its adaptation and transition to use within a commercial enterprise. Also, technological innovation precipitates changes in the internal processes, external relationships and the overall dynamics of enterprises that can, if sufficiently disruptive (e.g. the Internet), alter the course of industries and the broader economy.

The transformation of manufacturing has involved a broad mix of technologies applied to the full range of manufacturing activities and production processes. The "arsenal" of advanced manufacturing technology (or AMT) typically includes computer-aided engineering and design, computer-assisted manufacturing, product and production simulation, high-speed/high-precision tools and robotics, automated materials handling systems, and supply chain automation using Internet technologies. Through the implementation of AMT, and its blending with skilled employees and advanced

manufacturing processes, manufacturers have substantially increased the speed and flexibility of the overall production process while simultaneously lowering costs and improving product quality and customization – a combination of benefits that were largely unattainable under the traditional paradigm of standardized mass production.

The competitive advantages stemming from the application of technology to manufacturing has motivated increasing numbers of U.S. enterprises to employ AMT as the "cornerstone" of their manufacturing strategies. [35] As an indicator of the adoption of technologies in the AMT arena, it was reported last year that 80% of U.S. manufacturers use computer-assisted design to create new products and 64% use computers in manufacturing processes.[36] In addition, innovations spinning off from the information technology revolution have enabled manufacturers to transcend traditional organizational boundaries by greatly easing the flow and integration of information throughout the manufacturing enterprise and supply chain. In this way, the adoption of information technology in conjunction with the diffusion of technology-intensive manufacturing processes and the spreading use of advanced manufacturing methods has allowed for the seamless integration of suppliers, manufacturers, distributors and retailers into an extended or virtual manufacturing enterprise.[37] . Overall, the increased integration of the supply chain and the increased outsourcing of production opens new opportunities for sharing technology that can foster innovation as partners in the extended enterprise collaboratively seek competitive advantages in the "New Manufacturing" era.[38]

Sources of Technological Innovation for Manufacturing Enterprises

Manufacturers have multiple sources of technological innovation that often are employed synergistically. The interchange of technology within the extended enterprise serves as an important innovation source, as does the diffusion and spill-over of technologies from competing enterprises and related industries. Another key source, especially for manufacturers lacking significant internal R&D activities, are external knowledge centers, such as university, government and private laboratories. Lastly, the interplay of a firm's internal functions (e.g., research and engineering, marketing, and manufacturing) and its stock of intellectual capital, can provide a more direct source of technological innovation. The level of technological sophistication resident within the enterprise is of particular importance since "it takes knowledge to absorb knowledge"[39] and put technology to work.

Regardless of the immediate wellspring of innovation, technology primarily originates from formal R&D activities. Accordingly, the strong commitment of U.S. manufacturers to R&D has been a key component in the revival of U.S. manufacturing industries. Overall, the U.S. accounts for about 43% of the industrial world's R&D expenditures. And since 1980, industry has provided the largest share of U.S. R&D funding, providing an estimated $150 billion or 66% of the total R&D expenditures in 1998. In addition, U.S. manufacturers accounted for 77% of the total industry performance of R&D funded in the U.S. in 1997. However, while 18,130 companies in manufacturing industries were identified in 1997 as R&D performers, both the performance and funding of R&D is heavily concentrated in large manufacturing enterprises, such as 3M, General Motors, and IBM.[40] Thus, the world leadership of U.S. manufacturers in R&D provides a critical basis for innovation and competitiveness, yet the gross imbalance in R&D conducted across the

spectrum of small, medium and large manufacturers, along with those that are not engaged in R&D, contributes to the challenge of fostering innovation throughout U.S. manufacturing industries.

Another key consideration influencing the course of innovation in manufacturing is the growing globalization of R&D and innovation. Driven by competitive pressures to access technology and talent worldwide, U.S. industry is increasingly developing global arrangements for R&D and the implementation of technology.[41] For example, two leading electronics firms headquartered in the U.S. entered into a joint venture last year to create a "global 600 person R&D team focused on innovations in manufacturing technology" for the production of advanced integrated circuits.[42] Overall, the globalization of R&D is expanding the environment for stimulating innovation in manufacturing well beyond the traditional boundaries of nation-states.

Leading Technological Innovation in Manufacturing Enterprises

Given its criticality and complexity, technological innovation is a "process that must be optimized and not left to chance."[43] Drawing upon an extensive body of research, and the experience of manufacturers in particular, it is possible to distill several key considerations and practices that contribute to the successful leadership of innovation.

A clear success factor is the personal involvement and commitment of the enterprise leadership in providing the focus and sponsorship necessary for innovation. Manufacturers have achieved greater benefits when the implementation of technology is driven by an overall vision, clear strategy and defined objectives for improving the competitiveness of the enterprise.[44] For example, the CEO of Landrover set aggressive goals for the development of the new Freelander vehicle involving time to market and manufacturing flexibility. In doing so, he encouraged the project team to embrace new technologies in achieving the goals, resulting in the use of virtual reality technology that "enabled the design of superior manufacturing processes and facilities in half the traditional time."[45]

Another important function of innovation leadership involves the shaping of an enterprise culture and norms conducive to innovation. Accordingly, leading U.S. manufacturers, such as General Electric, have sought to transform themselves into learning organizations that seek "the best ideas regardless of their source" and to build diverse teams to exploit ideas and technology in new ways. [46] Overall, industry experience has shown that "organizational culture can be an important piece of the puzzle in implementing manufacturing technology," and should be assessed carefully to identify changes that may be necessary to order to foster innovation and achieve competitive benefits.[47]

Two other leadership responsibilities essential to fostering innovation involve the investment in human resources, and the implementation of managed processes to generate, acquire and implement technology on a continuous basis. For example, Caterpillar, in recognizing the need to promote innovation, recruits talent from top engineering and technical schools, and has established strategic research and learning partnerships with five leading universities worldwide.[48] Also, studies of U.S. manufacturers have found that employee training programs and positive labor/management relations are significant factors in the successful implementation of technology in manufacturing operations.[49] In tandem with investing in workforce knowledge and skills, sustainable innovation requires systematic processes that stimulate creativity across the functions of the firm, and provide

leadership and resources to move technology into productive uses that address enterprise priorities. In this way, and through other focused processes spanning the creation of knowledge to its technological implementation, innovation becomes a reliable, strategic means of advancing the competitiveness of manufacturing enterprises.

Conclusion

The experience of U.S. manufacturers has shown not only that technological innovation is a "vital weapon in world markets,"[50] but that it is a powerful force in the changing nature of production and manufacturing enterprises. This transformation is boosting the flexibility, agility and overall competitiveness of U.S. manufacturing enterprises and industries. U.S. leadership in manufacturing innovation, however, is neither assured nor automatic.

In order to maintain the competitive edge in technological innovation, several steps are recommended as ways to further bolster government and industry efforts to meet the innovation challenge. First, innovation leadership should be viewed holistically and firmly established as a core element of business education and executive training. The success of manufacturing enterprises will rely increasingly upon leadership that can create and optimize the conditions for innovation. Secondly, government should seek to address the imbalance in manufacturing R&D by further enhancing and targeting programs to broaden the participation of manufacturing enterprises in R&D and innovation. This can be done, for example, through augmenting the federal Small Business Innovative Research program to specifically increase the involvement of manufacturers, selectively sponsoring private/public R&D consortia in lagging manufacturing industries, reinforcing manufacturing technology extension and technology commercialization programs at the federal and state levels, and strengthening the federal R&D tax credit to further stimulate manufacturers of all sizes to undertake greater investments in innovation. Overall, in view of the critical importance of sustained and rapid innovation, and the possible erosion of national competitive advantages through the globalization of R&D, the U.S. must build upon its societal pre-disposition towards innovation, and work to ensure that American manufacturers as a whole utilize technology to unlock their potential.

America's Workforce for the 21st Century, Skilled Labor Shortage

CDR Paul Martinez and CAPT Francis Jouanjean

Manufacturing today is complex, competitive and quality conscious. Consumer demand for customization has replaced the earlier "one size fits all" notion of mass production. To deliver what customers want, manufacturers are not only using more technology, but are also reinventing themselves through the reorganization/restructuring of production processes and by reevaluating every aspect of production to improve productivity and gain competitive advantage. Manufacturers are now driven by a "faster, better, cheaper" mantra. Focused factories, lean manufacturing, mass customization and agile manufacturing are replacing the old notion of mass production and economies of scale.[51]

The industrial revolution, shaped traditional manufacturing in which the worker is viewed as unskilled and a servant to the machine -- focusing on accomplishing one explicit task.

Increasingly, with the infusion of technology and restructuring of manufacturing processes, the worker does not engage in mass production but in what might be called "team production"; workers are multi-skilled and expected to operate easily in cross-functional teams with little or no supervision.[52] In addition, due to flatter and less hierarchical organizational structures, manufacturers increasingly need workers with problem solving, decision making, and teamwork skills. In the new workplace, decisions once made in corporate offices are now made on the manufacturing floor. Within manufacturing, the advanced production processes highlight the strong demand for skilled workers: 84% of manufacturers use computer-aided design; 64% of manufacturers use computers in the manufacturing process, ranging from programmable machines to the integration of large scale production systems; and 63% of manufacturers use local computer networks to enhance productivity. [53]

Challenge – Need for Skilled Workers

The demand for skilled employees is a trend that will become increasingly more vital to the manufacturing sector. In the 1950's, according to the Department of Labor, 20% of the workforce could be classified as skilled labor, 60% as unskilled, and the remaining as professional workers. By 1997, these statistics had become inverted: only 20% of jobs were unskilled while 60% were skilled. As we begin the new millennium, one of the major challenges facing the manufacturing industry is the shortage of workers with the skills needed to keep pace with technology and maintain a global competitive advantage.

- In a 1997 survey by the National Association of Manufacturers, 88% of manufacturers reported a shortage of qualified workers in at least one job category. In the fall 1999, the NAM commissioned a survey of 4,500 manufacturers of all sizes about their concerns in hiring and retaining good workers. Of those responding, 50% stated their workers lacked basic math skills, 55% said their workers had difficulty with basic writing and comprehension skills, and over 60% said employees lacked basic job skills such as arriving on time and staying for the full work[54].

- A 1999 American Management Association survey of mid-size and larger businesses found that 38% of the job applicants taking employer-administered tests lacked skills necessary for the job for which they were applying. That percentage increased from 35.5% in 1998 and 22.8% in 1997– reflecting tighter labor markets and the rapidly rising demand for skills.[55]

- The National Tooling and Machining Association in August 2000 estimated that there were over 25,000 jobs going unfilled in U.S. machine shops resulting in manufacturers regularly passing up work because they did not have the capability to fill orders.[56]

The problem of a skilled labor shortage in the United States is complex due to a number of factors involving government, the manufacturing sector, demographics and public perception of manufacturing. Federal funding for training goes to displaced and disadvantaged workers, not to train incumbent workers or provide skill training. Because

of rigid and bureaucratic rules, it is difficult to use funds to support effective industry driven efforts to improve worker's skill levels. According to the American Society for Training and Development, company spending on training has not kept up with the need or pace of new workers. Considering that upgrading skills is becoming more vital in the 21st century than ever before, the shortfall could severely affect future industry growth.

Most manufacturers, but particularly, small and medium sized companies[57], have limited capacity to engage in significant and sustained workforce development efforts. They lack information on what kind of training firms need and where to get it, and more importantly lack sufficient funds to individually invest in this endeavor. As a result, when confronted with a shortage of skilled workers, most firms attempt to hire workers from other manufacturers.[58]

Complicating the issue is the perception of manufacturing being a dark, dirty, dead-ended industry where you cannot make a decent career/salary – this despite the fact that in 1998 total compensation in high technology/high trade manufacturing averaged $56,700 per worker, 35% higher than the average total compensation in the private sector.[59] Finally, today's highly skilled workforce is an aging population – in just a few years the cream of the workforce will be retiring. Since 1950, the average retirement age has declined from 67 to 63 and many in the baby boomer generation want to retire even sooner. As a society, we have encouraged people to retire at a younger age even though they are healthier and live longer than ever before and could remain in the workforce. Retirement has evolved from a short and necessary evil – a period in which people could no longer work and earn their way – into a sanctioned and cherished reward: a time to relax and to savor the pleasures of travel, family, etc.[60]

Policy Recommendations in Addressing Skilled Labor Shortage:

Collaborative efforts in which manufacturers working together in addressing the skilled labor pool shortage may well be the most efficient course to pursue. As previously stated, the majority of manufacturers are small/medium size companies, which do not have the resources available to pursue major training and/or recruitment efforts. By working as a consortium, all manufacturers can reap the benefits of shared saving, balanced risk and long term commitment vice their current practice of luring each other's workers with a raise and a promise. Solutions that manufacturers, with varying degree of assistance from government need to pursue are:
1) Ensuring that the future workforce has the proper skills by reaching out and fostering industry, community, education, and government partnerships. A key tenet of reaching out involves changing the current industry's image that exists of solely being a 1900 assembly line with no future growth potential. The best way to change the mindset of the next generation of workers is to establish a comprehensive public relations campaign aimed at area school counselors (high school and community college), school age young adults, their parents, and local community organizations (Kiwanis, American Legion, etc.), that creates an awareness of the change in manufacturing and of career benefits. Manufacturing recruitment processes also need to be improved to increase the number of students enrolling in technical programs thereby increasing the total eligible pool of employable people for manufacturing. This involves the establishment of apprenticeship programs for senior high school and community college students that create a seamless career path leading from the classroom to

the workplace -- upon graduation resulting in positions as technicians and/or manufacturing engineers. Manufacturers can also provide summer internship programs to introduce students and their parents to what manufacturing work is really like. By bridging the gap between the classroom, postsecondary education, and the workplace, students can better understand the implications of their studies, it heightens their interest in learning and excels their motivation to succeed. Finally, manufacturing, in concert with local community colleges and high schools, needs to assist in helping schools create and develop curricula in basic manufacturing skills. The end goal is narrowing the skill gap and preparing students for the manufacturing jobs of the future.

2) Training or retraining workers who are already out of the formal education system. Investments in worker training pay off for the employer in the long run by raising their productivity, necessitating the commitment to continuous training as part of an employee's career. As the job market tightens for skilled labor, it will be necessary for companies to adopt more elastic hiring standards and invest more in developing employee skills. Government assistance, in the form of tax credits, would encourage manufacturers to train their first level managers and non-supervisory employees. Increasing credits for manufacturers who use state certified education/training institutions would strengthen relationships between the industry and certified training providers.[61]

3) Adoption of nationwide skill standards would benefit the industry by specifying the necessary competencies required to succeed in manufacturing trades. This allows manufacturers to clearly determine existing shortages and provides a basis to determine hiring, education and training requirements for current and entry level workers. Skill standardization also benefits the employee by ensuring he/she possesses the transferability of skills in the event a worker relocates -- more importantly, it provides a delineated career path for individuals to follow; and requires manufacturers to clearly document a worker's skill level that currently does not exist.

4) Government increasing immigration and lifting of caps on the H1-B visa program and/or extending departure deadlines on existing visas. The program is designed to allow highly educated professionals to work in the high tech manufacturing industry; permitting companies to higher a limited number of qualified individuals for up to six years in "specialty occupations" such as engineering.

5) The introduction of emerging technologies that make capital investment distinctly more profitable, enabling firms to substitute capital for labor while simultaneously increasing productivity. The Federal Reserve and Congress can stimulate capital investment by reducing interest rates, or passing legislation that provides tax incentives in the form of allowing expenditures for labor reducing technologies to be deducted at time of purchase.

Conclusion:

A skilled productive workforce is unquestionably the most important raw material for any manufacturer and the most difficult challenge that we as a nation will face in the

beginning of the 21st century. As the U.S. population becomes more diverse and global expansion increases, manufacturers cannot afford to underutilize any segment of the American talent pool. To remain competitive today, a manufacturer must invest a tremendous amount in maintaining and developing the skill levels of employees. This is not a proposition that manufacturers will be able to meet alone due to financial and institutional limitations. In the end, it will require an effective consortium of business, government, and education leaders, working as a team banding together to address this national challenge. Innovative approaches will be required to address this crucial problem.

Green Manufacturing

Capt. Shinichi Tokumaru and LTC Mike Clay

Purpose**.** The purpose of this essay is to examine the environmental compatibility of current manufacturing processes, explore technological advances and viable alternatives, and propose policy options that maximize U.S. economic potential while protecting the environment.

Background. Environmental degradation is a transnational threat. America's rapid industrialization significantly contributed to widespread damage to the air, water, and soil. *Dirty* processes were used in the production of iron, steel, petroleum products, pulp, paper, wood products, plastics, and manmade fibers. Although much progress has been made to develop and implement environmentally-compatible manufacturing processes, America is still the world's largest producer of noxious emissions.

Green Manufacturing Defined**.** Green manufacturing is the application of environmentally-compatible manufacturing materials, technologies, and processes. "Environmentally benign manufacturing will become one of industry's greatest strategic challenges, not only from an engineering perspective, but from a business and marketing perspective as well."[62] The U.S. manufacturing industry generates significantly more waste than any other industry. This trend cannot continue if our industries are to survive in an increasingly competitive environment.

Scope of the Problem. Inevitably, the global environment will become further degraded if developed countries do not modify production practices and consumption patterns now. Although scientists have not reached consensus, the destruction of the ozone layer, acid rain, and global warming would have severe, long-lasting consequences for populations and nations beyond the borders of the countries producing the pollution.[63]

Timeline for Action. The United Nations estimates that the world population will increase from 5.7 billion in 1995 to 10.4 billion at the end of this century. The most rapid increase will occurr in the first half of this century. [64] Decisions regarding natural

resources and pollution must be made now if we are to ensure a reasonable quality of life for future generations.

Incentive for Action. In the U.S., many multinational companies are cognizant of impending overseas environmental regulations and growing consumer demand for environmentally friendly products and are formulating responses. Some have embraced the notion that environmentally friendly products and production techniques are competitive weapons. But many manufacturers, especially smaller firms in the U.S., are far behind in acknowledging and addressing the environmental concerns of consumers and governments. [65]

Case Study – The Automotive Industry. Auto production is the largest manufacturing industry in the U.S. Over 70% of a car is made of recycled ferrous metals; 21% is non-metal; 9% is non-ferrous metal. New technologies have enabled auto-makers to greatly reduce emissions. Motor vehicle assembly operations produce little hazardous waste; however, significant amounts of waste are produced in the manufacturing process. Manufacturers striving to meet consumer demand for "greener" cars have developed the hybrid car. They are developing a comprehensive assessment for each model that identifies the environmental costs for each stage of the car's life cycle. This process, when complete, will give the consumer visibility of the vehicle's total environmental cost from conception to production and through to the car's retirement. Eventually, consumers will likely see an environmental price tag in the window along side the standard financial pricing information. Marketing will emphasize the fact that the product was manufactured in a green facility.

Strategy for a Sustainable Future -- CTES. The U.S. must exercise a leadership role in protecting the global environment. In order to deal with these issues adequately and still maintain economic growth, the U.S. must change our current economic system that encourages mass production, mass consumption, and mass waste. Accordingly, a new Circulated Type Economic System (CTES) is needed to focus on **recycling**, **reduction** of use of energy, materials, and resources and reduction of waste, and **reuse** of parts of products. [66] Recycling, Reduction, and Reuse (R3) will integrate the economy, industry, and environment in such a way as to minimize the need for environmental and resource restrictions.

Integration of Environment, Economy, and Industrial Activities. The basic elements of the nation's CTES strategy should be minimization of usage and minimization of discharge. Using reusable resources and energy can reduce use of natural resources and energy in industrial activities. Minimization of waste associated with manufacturing processes must focus on greenhouse gas, detrimental chemicals, carbon dioxide, dioxin, heavy metals, and nitrogen oxide. [67] The U.S. must maximize the efficient use of natural resources and energy, minimize waste, extend the lifetime of products through the activities of production and consumption, produce only the products that we need, use (not consume) them as long as we can, and recycle them. These objectives will not be achieved by industry alone. The U.S. needs to partner with companies, consumers, and governments. In addition, the U.S. must create advanced technologies and new environmental friendly products. Minimization will be essential. Advanced manufacturing will be a key means in achieving these objectives.

Partnerships: Companies, Consumers, and Government

Consumers and manufacturers are the main pillars of the CTES that, in conjunction with government, must play active roles in preparing the marketplace. Manufacturers must make educated decisions regarding manufacturing practices and know the environmental impact up front. Consumers must be made to appreciate the positive consequences of purchasing environmentally friendly products and recycling. The government's role is to establish competitive market conditions that complement the efforts of consumers and manufacturers. The partnership among companies is also important. In order to make full use of natural resources manufacturers must share best practices in order to reduce waste and consumption.

This type of cooperation will not be widespread until the government provides incentives for cooperation. The government should: foster innovative technical developments that are undertaken by industry because of high risk; aggressively acquire environmental friendly products (e.g., the GSA Federal Supply Service already offers a wide range of environmentally oriented products and services);[68] promote information exchange about product waste among companies; assist non-governmental organizations in supporting environmentally-friendly products and establish the systems that allow consumers to easily distinguish them (e.g., eco marks).

Establishing New Advanced Technology

CTES requires new industrial technologies that reduce the environmental load throughout the full cycle of production from the extraction of natural resources to production of materials and parts and through distribution, consumption, recycling and disposal.[69] The U.S. must promote innovation throughout innovate the production life cycle that is environmentally friendly. To accomplish this objective, industry must create and implement new technologies to minimize the use of natural resources and energy by reducing waste generation and reusing parts and components. The government should support these industrial activities by developing new materials that enable long- term use, creating new materials that will return to nature easily, developing the materials that are easy to recycle, and establishing the production process that will minimize the usage of resources

Conclusion. In the past, national policy-makers and industry leaders have regarded protection of the environment and restrictions on use of natural resources as a drain on the nation's economy. As a result, the tendency has been to not take action until problems clearly emerge.[70] The U.S. must reverse this reactive mentality and proactively implement R3 as a whole society, including individuals, industry, and the government. Development of the CTES must accompany the establishment of new industrial technologies, materials and processes that will minimize the burden on the environment. Such efforts would create competitive advantages for U.S. industry, and contribute to solving the global problems associated with environmental degradation and resource scarcity.

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