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by
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Manufacturing is an essential part of our economy. Not only are manufactured goods the currency of world trade, but manufacturing is what creates wealth. It adds value to resources by making them do something more, which is something that services cannot do.

For most of the 20th century, manufacturing was based on the Henry Ford assembly line model. Each worker carried out the same small task over and over, and a standardized product rolled off the end of the line, each one identical to the one before. Few of the workers in those manufacturing plants had more than a high school diploma–if they even had that. Then, about three decades ago, global competition for manufacturing jobs began to heat up. Many companies realized that large pools of unskilled labor willing to work for much lower wages than those in the United States could be accessed by moving plants overseas. This led to a large scale shift of jobs out of our country. In part due to this out-migration of jobs, manufacturing accounted for only 14 percent of the U.S. Gross Domestic Product in 2001, down from 27 percent in the middle of the twentieth century. Manufacturing jobs declined from 30 percent of our workforce to less than 15 percent.

However, these numbers mask a second major shift that occurred in the manufacturing industry in the 1980s and 90s. The manufacturing processes themselves began to be fundamentally changed with advances in technology, and this was accelerated with the invention of the microchip. Manufacturers rapidly adopted new technology that reduced the need for manpower, while at the same time they integrated new management techniques that called for more sophisticated and adaptable workers. This led to a vast family of production tools that offer unmatched precision, quality, and efficiency – from CAD-CAM to "just in time" and "demand-pull" manufacturing. The new technology that has infused manufacturing is capital intensive rather than labor intensive. Robotic arms now assemble products. Automated guided vehicles (AVGs) move supplies and products around the plant. Real-time communication feeds information back into the process in time to reduce the margin of defects to virtually zero. Salespeople with cell phones and laptop computers cover more territory in less time, and sophisticated logistics systems speed the products on their way. The entire process, from designing the product to shipping it, has been computerized. The skill levels expected of workers are now far beyond that of earlier eras.

The remarkable changes brought about by new technology have enabled manufacturing to outpace other sectors of the U.S. economy in productivity. Between 1977 and 2001, overall U.S. manufacturing output, measured in constant 1996 dollars, almost doubled. While productivity for the U.S. economy as a whole increased by 53 percent, manufacturing productivity rose 109

percent. Over the course of the past 25 years, overall prices rose by 140 percent, but productivity increases held the increase in the cost of manufactured goods to 60 percent.

The combination of increased automation and greater productivity meant manufacturers could meet market demand with fewer employees, so that instead of moving overseas as they had during the 1970s and 1980s, many manufacturing jobs actually began to disappear entirely. What has been happening in manufacturing is analogous to what happened previously in agriculture, which saw an ever-shrinking number of farmers feed an ever-growing world population. Data back this theory up, as manufacturing jobs have been shrinking not just in the United States but everywhere. Estimates are that 22 million manufacturing jobs disappeared worldwide between 1995 and 2002. A new buzzword appeared in the manufacturing community – "lights-out" plants – referring to facilities that are so automated that there is no one around who needs to see what they are doing. Even though advanced technology caused them to shed jobs, recent research indicates that had American manufacturers not moved rapidly to incorporate new technology and improve their competitive posture, the U.S. manufacturing sector would have lost even more jobs as more manufacturers closed their doors entirely.

At Georgia Tech, we see these factors reflected in the detailed survey of the state's manufacturers that we conduct every few years. We are presently in the middle of the 2005 survey, so 2002 is the latest for which we have final data. However, when you compare the 2002 data with the 1999 data, about half of Georgia's manufacturers underwent major changes in strategy or structure during that three-year timeframe. Most of these changes involved innovation and/or technology, and were aimed at quick delivery, adapting to customers, and providing value-added services.

The 2002 survey showed that companies with new-to-the-industry products, value-added service offerings, and substantial employee use of computers had significantly higher growth, profitability, and productivity than those who did not engage in these practices. About 60 percent of Georgia's manufacturers do some type of new product development, and more than one in five are developing products that are new to their industry. These companies who are innovating have significantly higher growth, profitability and productivity rates. Manufacturers filing patent applications – another measure of innovation – also had significantly higher return on sales. Those who introduced new processes experienced significantly higher return on sales and growth in value-added per employee, and firms with Web-based customer/supplier linkages or ordering capabilities had significantly higher returns on sales.

We have traditionally thought of factories as dusty, greasy, and full of rows of people operating clanking machinery. However, while manufacturing of that sort may still be needed to make some products, it will fall at the lower end of the economic spectrum, which we will cede to others. American manufacturing of the future will need to be focused on the high end of the economic spectrum if we want to maintain our standard of living. We will need to pioneer new manufacturing techniques and focus on the highest-possible leading-edge precision technological work that it is not possible to do in other parts of the world. The strategies even of the latter part of the last century – cost control, "total quality," and continuous productivity improvement – will not be enough. To win in the 21st century will require flexibility, collaboration, customization, precision, global market savvy and speed. To quote a recent statement on "Ensuring

Manufacturing Strength through Bold Vision" by the leaders of the National Science Foundation, "The big winners in the increasingly fierce global scramble for supremacy will not be those who simply make commodities faster and cheaper than the competition. They will be those who develop talent, techniques, and tools so advanced that there is no competition."

During 2004, I was privileged to serve as co-chair, together with IBM CEO Sam Palmisano, of the National Innovation Initiative, sponsored by the U.S. Council on Competitiveness. We involved 400 of the nation's best minds from academia, industry, and government in developing an action agenda designed to help the United States create an economy based on innovation. The National Innovation Initiative generated 30 recommendations that we grouped under three broad topics: talent, which is the human dimension of innovation; investment, which is the financial dimension of innovation; and infrastructure, which provides the enabling framework for innovation. All three of these have a bearing on the competitiveness of American manufacturing, so I will touch briefly on each one.

High-tech manufacturing operations require employees with a much higher level of skills. For example, technology and processes at the Timken Company, which is the world's leading manufacturer of roller bearings, have become so sophisticated that the company now looks for workers with bachelor's degrees for many of its entry-level positions. Georgia Tech's survey of Georgia manufacturers has identified human resource problems as their foremost worry. Yet the United States is falling behind in the education of technology workers. China, India, and the European Union each graduate more engineers than the United States and the gap will continue to grow based on present trends. Also, our past ability to rely on ample supplies of international science and engineering graduates will be tested as more of these students are enticed to take jobs in the growing technology businesses at home, and as increasing numbers simply choose not to study here because of concerns about post 9/11 visa and export control policies.

One of the primary investments in innovation is R&D. In January of 2004, the Department of Commerce released the results of a series of roundtable discussions held with manufacturers around the nation. Among the areas that manufacturers believe require immediate attention is a commitment to sustained and balanced R&D to ensure that the federal government reinforces rather than hinders innovation and bringing new ideas to market.

About the same time the Department of Commerce published its report, another report was released by the Subcommittee on Information Technology Manufacturing and Competitiveness of the President's Council of Advisors on Science and Technology (PCAST), chaired by George Scalise, president of the Semiconductor Industry Association. The PCAST report pointed out that as the speed of technology development accelerates, the linkage between research and manufacturing becomes much closer. Locating a manufacturing plant close to an R&D operation that is generating new process and product ideas facilitates the human interchange that speeds ideas from the lab to the marketplace. As a result, places with both strong R&D centers and manufacturing capabilities have a competitive edge. The good news is that some semiconductor manufacturers have remained in the United States rather than moving overseas despite the cost benefits of off-shoring, because they want to be close to the university R&D that is driving new developments. The not-so-good news is that the level of R&D being conducted in countries like China and India is improving and many U.S. and global companies are building R&D facilities

in these countries. This means competition may increase for the more sophisticated manufacturing jobs as well, and if this is so, the United States may end up with a security problem as well as an economic problem.

The present technological superiority of the United States has flowed from the strong investments we made in scientific research since World War II, and that lesson has not been lost on those who aspire to compete with us. We need not only to consider improving investment levels in R&D, but also how they are distributed. A recent PCAST report showed that funding for research in key areas of engineering and physical sciences have declined while levels in other areas increased. In a world where future manufacturing developments will come from interdisciplinary research, care must be taken to support an appropriate funding portfolio.

As a part of the third topic, infrastructure, the National Innovation Initiative looked specifically at strengthening America's manufacturing capacity. We were concerned because while the United States remains the world's leading nation in the production of manufactured goods, our rate of growth in manufacturing production has remained virtually flat over the past four years. During the same timeframe, 2000–04, Asia (excluding Japan), Central Europe and the Balkans, and Latin America experienced strong growth in manufacturing production. Our high-end competitors – Western Europe and Japan – also outperformed us.

The National Innovation Initiative calls for the United States to design and implement a new foundation for high-performance manufacturing production. That means new human, organizational, financial, and policy models must be developed. New designs, processes, and materials need to be introduced and new manufacturing technologies should be brought to the production cycle more rapidly. We are moving in that direction, with flexible automation, complex numerically controlled tooling, precision engineering, distributed manufacturing, e-commerce to connect and manage supply chains, materials databases, and shared-use facilities for R&D and pilot production, which lowers the risks and barriers to entry. Technologies like these will not only increase productivity even further, but will also help to offset lower wages in other countries.

As a technological university, Georgia Tech has a wide range of experts devoted to evaluating what is happening in manufacturing, divining future opportunities for this core industrial sector, and developing the manufacturing technologies and methodology of the future. Several important themes are emerging from their work.

First, manufacturing technologies of the future will include molecular and nano-manufacturing, bio-materials and bio-processing, micro-electro-mechanical systems (MEMS), free-form fabrication, and new software control technologies. Ideas that will come more strongly to the fore include innovation, knowledge management, customer relationships, and waste reduction – not only in the manufacturing process, but also over the life of the product.

These technologies and ideas are expected to be expressed in the context of several inter-related trends, including movement away from mass production toward semi-customization; shifts away from centralized production locations to distributed sites; and the transformation of centralized business control toward collaborative relationships between distributed sites.

We can already see the trend toward customized manufacturing in the ability to order customized clothing from manufacturers like Land's End or L.L. Bean, and the opportunity for customers buying a car to send their specifications to the factory online rather than compromising on what a dealer happens to have on the lot. The next stage is expected to be "additive manufacturing," which enables end-users to participate in the design of more sophisticated products like hearing aids, dental restorations, eye glasses, and joint replacements. Additive manufacturing holds potential to embody an entire manufacturing system within a single, small machine. That has led some to predict that additive manufacturing machines for certain purposes will be introduced for use in the home within the next decade or two.

Even as manufacturing machines become smaller, so will the scale on which manufacturing takes place. Already the United States has seen a significant drop in machine tool production, which paralleled a significant decline in R&D spending in this area, as attention has shifted to microscale tools and machining. Nano-manufacturing is the place where nanotechnology will transform from an exotic research field to something that reaches out to touch all human civilization. Nano-manufacturing addresses not only work on the nano-scale, which is one-billionth of a meter, but also the engineering of new materials at the atomic and molecular level that have novel, unique, and improved physical, chemical, and biological properties. Nanoscale engineering can greatly expand the range of performance of materials and chemicals, as well as creating microscopic machines and systems.

Nano-manufacturing has the potential to impact virtually every human-made object, from automobiles to electronics, from advanced medicine to energy production. Three specific areas in which we are working at Georgia Tech are nano-computers that utilize nanotubes as interconnections instead of transistors; disease diagnosis and controlled drug delivery; and optoelectronic materials. But successful implementation of nano-manufacturing will require standard measurements at the atomic level, special manufacturing environments, and micro-scale technologies and quality control mechanisms. It will also require the involvement of experts in a much wider range of disciplines than traditional manufacturing – including electrical engineers, physicists, chemists, biologists, and biomedical engineers.

Even as the leading edge of American manufacturing moves to unprecedented levels of sophistication, there are segments of the industry that cannot and should not be left behind. America's traditional manufacturing industries still have a relatively strong presence in our nation's economy, and attention must be given to their competitiveness. The U.S. pulp and paper industry, for example, generates $100 billion of shipments a year – 30 percent of the world's production. Technological innovation is important to keep such traditional industries competitive.

The growing need for the rapid development and deployment of very sophisticated manufacturing technology and techniques is particularly challenging for the nation's 350,000 small and mid-sized manufacturers, who employ more than seven million people and comprise nearly half of the U.S. manufacturing base. These companies often lack the information, expertise, time, and money required to engage in the constant innovation and upgrading required to do well in today's competitive marketplace. However, with some timely assistance, they can

also succeed. For the past 40 years, Georgia Tech has operated a state-supported network of industrial extension offices that serve Georgia's small and mid-sized manufacturers, and as part of our surveys of Georgia manufacturers we have tried to assess the benefits of that service. What the 2002 survey showed was that companies assisted by Georgia Tech had comparatively higher productivity – an average value-added increase of $3,000 per employee.

Finally, changes in manufacturing processes have significant logistics implications. The U.S. trucking industry transports more than three-quarters of the freight in the country, and changes in the manufacturing process have major consequences for the logistics of moving those loads. The trucking industry has already had to make significant adjustments to facilitate the implementation of just-in-time manufacturing, which requires greater load and time precision, and more recently just-in-case policies designed to prevent and address unexpected disruptions in the increasingly tightly engineered supply chain. Future changes will require even more logistical sophistication.

The competition for manufacturing jobs and new applications and technology is going to grow in the future. We have to adjust to a changing landscape, and re-commit ourselves if we are to compete with nations that will have larger technological workforces and wage advantages for some time to come. Fortunately, the United States still has an edge and our society supports entrepreneurism and risk taking. However, the window of opportunity will be open only so long, and we need to take action now if we are to succeed.