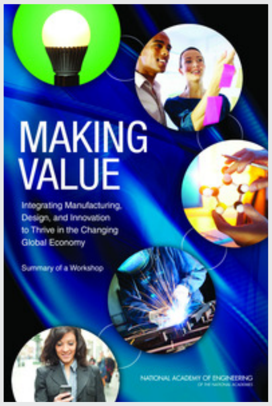

Making Value: Integrating Manufacturing, Design, and Innovation to Thrive in the Changing Global Economy: Summary of a Workshop

DETAILS

66 pages | 6 x 9 | PAPERBACK
ISBN 978-0-309-26448-8 | DOI 10.17226/13504

CONTRIBUTORS

Kate S. Whitefoot and Steve Olson, Editors; National Academy of Engineering

MAKING VALUE

Integrating Manufacturing, Design, and Innovation to Thrive in the Changing Global Economy

Summary of a Workshop

Kate S. Whitefoot and Steve Olson, *Editors*

NATIONAL ACADEMY OF ENGINEERING
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

THE NATIONAL ACADEMIES PRESS 500 Fifth Street, NW Washington, DC 20001

This project was supported by a generous gift from Robert A. Pritzker and the Robert Pritzker Family Foundation. Any opinions, finding, or conclusions expressed in this publication are those of the workshop participants.

International Standard Book Number 13: 978-0-309-26448-8
International Standard Book Number 10: 0-309-26448-0

A PDF version of this report is available at *www.nap.edu*.

Copies of this report are available from the National Academies Press, 500 Fifth Street, NW, Keck 360, Washington, DC 20001; (888) 624-8373 or (202) 334-3313; *www.nap.edu*.

For more information about the National Academy of Engineering, visit the NAE home page at *www.nae.edu*.

Printed in the United States of America

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

www.national-academies.org

WORKSHOP STEERING COMMITTEE

LAWRENCE D. BURNS (*Chair*), Professor of Engineering Practice, University of Michigan
CURTIS R. CARLSON, CEO, SRI International
NICHOLAS M. DONOFRIO, IBM Fellow Emeritus and (Retired) Executive Vice President, Innovation and Technology, IBM Corporation
ANITA GOEL, Chairman and Scientific Director, Nanobiosym; Chairman and CEO, Nanosym Diagnostics
SUSAN R. HELPER, Chair, Economics Department, and AT&T Professor of Economics, Case Western Reserve University
MICHAEL F. MOLNAR, Chief Manufacturing Officer, National Institute of Standards and Technology (NIST)
PANOS Y. PAPALAMBROS, Executive Director, Interdisciplinary and Professional Engineering, Donald C. Graham Professor of Engineering, and Professor of Mechanical Engineering, University of Michigan
JONATHAN J. RUBINSTEIN, Former Executive Chairman and CEO, Palm, Inc.
JEFFREY SMITH, Professor of Economics, University of Michigan
CHAD SYVERSON, Professor of Economics, University of Chicago Booth School of Business
REBECCA R. TAYLOR, Senior Vice President, National Center for Manufacturing Sciences

Staff

KATE S. WHITEFOOT, Program Director and Senior Program Officer
LANCE A. DAVIS, Executive Officer
PROCTOR P. REID, Director, Program Office
CAMERON H. FLETCHER, Senior Editor
PENELOPE J. GIBBS, Senior Program Associate

Preface

Manufacturing is in a period of dramatic transformation. But in the United States, public and political dialogue is simplistically focused almost entirely on the movement of certain manufacturing jobs overseas to low-wage countries. The true picture is much more complicated, and also more positive, than this dialogue implies.

After years of despair, many observers of US manufacturing are now more optimistic. A recent uptick in manufacturing employment and output in the United States is one factor they cite, but the main reasons for optimism are much more fundamental. Manufacturing is changing in ways that may favor American ingenuity. Rapidly advancing technologies in areas such as biomanufacturing, robotics, smart sensors, cloud-based computing, and nanotechnology have transformed not only the factory floor but also the way products are invented and designed, putting a premium on continual innovation and highly skilled workers. A shift in manufacturing toward smaller runs and custom-designed products is favoring agile and adaptable workplaces, business models, and employees, all of which have become a specialty in the United States. Future manufacturing will involve a global supply web, but the United States has a potentially great advantage because of our tight connections among innovation, design, and manufacturing, and also our ability to integrate products and services.

The National Academy of Engineering normally conducts studies at the request of government and delivers its conclusions to the requesting agency. In this case, the NAE has been sufficiently concerned about the issues surrounding manufacturing—and sufficiently excited by the prospect of dramatic change—to take action on its own. On June 11–12, 2012, it hosted a workshop in Washington, DC, to discuss the new world of manufacturing and how to position the United States to thrive in this world. The workshop steering committee focused on two particular goals.[1] First, presenters and participants were to examine not just manufacturing but the broad array of activities that are inherently associated with manufacturing, including innovation and design. Second, the committee wanted to focus not just on making things but on making value, since value is the quality that will underlie high-paying jobs in America's future.

The workshop opened with presentations on the changing nature of manufacturing, design, and innovation; the future of work; building the ecosystem for manufacturing, design, and innovation; and manufacturing for sustainability. The remainder of the workshop consisted largely of two extended breakout sessions, followed by reports of the breakout deliberations to the entire group. During the first breakout session, workshop participants split into six groups to discuss the following topics:

- The relationship between making things and making value
- Productivity, innovation, and business practices
- The role of geography in creating and capturing value
- Enabling the workforce for the future of manufacturing, design, and innovation
- Building the institutional structure for manufacturing, design, and innovation
- Opportunities for making value

The next morning, workshop participants divided into three groups to discuss the concept at the heart of the workshop: making value through the integration of manufacturing, design, and innovation, to which the workshop participants added a fourth critical factor: services associated with manufacturing, design, and innovation.

This summary of the workshop, written by Kate S. Whitefoot and Steve Olson, captures the main themes that emerged from more than 14 hours of presentation and discussion sessions. Given the overlap of the issues and topics discussed between sessions, this summary is organized topically rather than chronologically to provide a more readable account of the workshop. The views conveyed in the report are those of individual workshop participants and should not be seen as conclu-

[1] The steering committee's role was limited to planning and convening the workshop.

sions or recommendations of the planning committee or the National Academy of Engineering.

The National Academy of Engineering plans to initiate specific actions to extend this dialogue and strengthen the extremely important US innovation-generating machine. Other organizations should do likewise. Together, we can inaugurate a new era of advanced innovation, design, manufacturing, and service to make value in the United States.

Charles M. Vest, President
National Academy of Engineering

Acknowledgments

This summary has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Academies. The purpose of the independent review is to provide candid and critical comments to assist the NAE in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We thank the following individuals for their review of this report:

Alice Agogino, University of California, Berkeley
Gary Cowger, GLC Ventures, LLC
Joseph A. Heim, University of Washington
Christopher Johnson, GE Global Research
Stephanie Shipp, IDA Science and Technology Policy Institute

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the views expressed in the report, nor did they see the final draft of the report before its release. The review of this report was overseen by Julia M. Phillips, Director, Nuclear Weapons S&T Programs, Sandia National Laboratory. Appointed by NAE, she was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authors and NAE.

In addition to the reviewers, many other individuals assisted in the development of this workshop summary. Penelope J. Gibbs prepared the layouts; Greg Pearson, NAE senior program officer, coordinated the review; and Gina Adam, Christine Mirzayan Science & Technology Policy Graduate Fellow, assisted with the response to review. Additional thanks are due to Clair Woolley and Jim Gormley for their generous help with the production of this workshop summary.

Contents

BOXES: INDUSTRY-SPECIFIC EXAMPLES AND RELEVANT DISCUSSIONS

1

Making Value Through Integrated Innovation, Design, Manufacturing, and Service

THE OPPORTUNITY

Today's economy is marked by unlimited opportunities to engage in high-value innovation, said Curt Carlson, the chief executive officer of SRI International, in his opening keynote address. Despite the loss of US manufacturing employment over the past three decades, new markets and new opportunities abound. Rapidly advancing technologies such as synthetic biology, advanced robotics, regenerative medicine, advanced sensors, additive manufacturing, and direct digital manufacturing are transforming not just manufacturing but entire approaches to value creation (Box 1-1). "I have never seen more big opportunities in my life for innovation," he said. "Every field is wide open."

The communications sector demonstrates obvious examples of the ongoing transformation, said Carlson. Cloud computing and other technologies are creating entirely new opportunities for devices and services. Social media are connecting people in new ways. Similar observations apply in health care, education, energy production, transportation, and many other sectors.

To take advantage of these opportunities, many aspects of the US economy and US policies need to change, said Carlson. The US economy is "stuck" and the nation is drowning in debt. In 2008 the United States led the world in competitiveness. Now it is number five and dropping.

Large companies in the United States used to survive for many decades; now they last less than two on average, Carlson observed.[1]

[1] Foster, R. N., and S. Kaplan. 2001. *Creative Destruction: Why Companies That Are Built to Last Underperform the Market—and How to Successfully Transform Them.* New York: Currency/Doubleday.

BOX 1-1
Spotlight on Biomanufacturing: Opportunities and Needs for Value Creation

John Dordick, Howard P. Isermann Professor of Chemical and Biology Engineering and director of the Center for Biotechnology and Interdisciplinary Studies at Rensselaer Polytechnic Institute, talked about a specific area in which advanced manufacturing can change the world: biomanufacturing. Success in biomanufacturing means learning from and improving on the incredible capabilities already found in nature. The biosphere can create everything from the small molecules required for the functioning of cells to single organisms (the fungal mycelia) more than a mile across. "Nature does a remarkable job of biomanufacturing," Dordick said.

A 787 jet and a cell have about the same number of parts, according to Dordick, but biologists still have vast gaps in their knowledge of how cells operate. Nevertheless, people have been learning how to adapt biological processes to human purposes since our distant ancestors began fermenting liquids and drinking them. Biological processes are used to produce fructose, antibiotics, biofuels, industrial chemicals such as acrylamide and isoprenes, and many other products. Furthermore, the discipline known as synthetic biology, through essentially a modular plug-and-play technology analogous to apps for a mobile phone, offers the hope of creating biological factories for a virtually unlimited number of products.

Dordick discussed three opportunities in particular: bionanotechnology, safe biopharmaceuticals, and personalized medicine.

Bionanotechnology brings together nanotechnology, biotechnology, robotic technologies, microscale systems, and nanoscale systems to form hybrid systems with very specific functions. It offers the hope of developing nanoscale science and engineering to produce biomolecular and chemical building blocks and assembling them in a

Seven years ago, MySpace was the hot technology company, not Facebook. Long-standing companies such as Motorola and Hewlett-Packard are in turmoil. In a world characterized by intense competition, rapid exponential improvement, and unlimited opportunities, value needs to be created faster and in ways that customers want.

variety of forms. It may, for example, yield scaffolds for tissue regeneration, tiny sensors to monitor what happens in the human body, or agents effective against drug-resistant human pathogens.

Safe biopharmaceuticals represent one of the fastest growing segments of the pharmaceutical market. These are complex molecules designed to be safe and effective for the treatment of diseases such as cancer, arthritis, or multiple sclerosis. For example, Dordick and his colleagues have been working on a process to manufacture the coagulant heparin, which is extracted from pig intestines, that would offer many advantages over the traditional source.

Personalized medicine takes this idea farther by investigating the need for drugs on demand that are tailored to each individual. In cancer treatment, the results of a tumor biopsy can point to a specific treatment that is likely to be more effective than others for a particular patient. As researchers learn more about the mechanisms that cause disease, this approach could yield very specific treatments that are customized to the specific form of an individual's disease.

The major barrier to these technologies is the lack of a business model that can drive them. Developing a single drug can cost well over $1 billion, but in the future drugs will treat smaller and smaller groups of people. Developing a drug for each of these small groups, using current approaches, will be prohibitively expensive.

Transforming the pharmaceutical industry from large volumes of a relatively small number of products to small volumes of a very large number of products will require fundamental changes. Safety testing will need to become quicker and cheaper while delivering safer drugs. Because complete safety can never be guaranteed, people will need to understand the risks and benefits of any new drug or diagnostic. Close links between R&D and manufacturing will be critical to make pharmaceuticals efficiently and safely. No business plan currently exists for personalized medicine, Dordick observed, despite rapid advances in science and manufacturing techniques.

A harmful myth is that value creation is the result of luck or a lone genius. Value creation needs to become a discipline, Carlson said. "It is something that can be learned and proved and taught." If the necessary skills are disseminated, valued, and supported by an effective innovation "ecosystem," jobs will increase. He pointed out that many of the necessary fundamentals are present in the United States: the nation has a positive culture for innovation and entrepreneurship, abundant sources of energy, and a strong R&D infrastructure. But, he added, changes in business processes, education, infrastructure, and government services are essential to take advantage of these inherent strengths.

TECHNOLOGY AND THE TRANSFORMATION OF WORK

Productivity growth in the United States has been accelerating for the past three decades—from 1.6 percent per year in 1980–1989 to 2.1 percent in 1990–1999 and 2.5 percent in 2000–2009. Yet the median income (the point at which half of employees earn more and half less) has been flat for the past decade, and in 2010 fewer Americans were working than in 2000.

Both of these trends have a common cause, said Erik Brynjolfsson, director of the Center for Digital Business, Schussel Family Professor of Management, and professor of information technology at MIT's Sloan School of Management: rapid technological change. Technologies are now changing so rapidly that the skills of American workers and the structures of US organizations are not keeping up.

Gary Cowger, chairman and chief executive officer of GLC Ventures, LLC, and former group vice president of manufacturing and labor at General Motors, illustrated the influence of advancing technologies by describing how work changed over his four-decade career in the automotive industry (Box 1-2). Today, approximately 1,500 people in an automobile assembly plant do the work that about 5,000 did in 1965. This was made possible by the development of robotics, high-speed computers, and advanced sensor technologies together with processes—such as design for manufacturability and lean manufacturing—that made the implementation of these technologies effective (Figure 1-1).

The digitization of work is happening throughout the economy, Brynjolfsson said. Technology is changing rapidly and producing tremendous amounts of new wealth. But much of that wealth is going to a small portion of the population. "There is no economic law that says when technology creates wealth that everybody has to benefit equally. Or even that everybody has to benefit, period. It is entirely possible for the pie to grow and for some parts of the pie to get bigger and other parts of it to shrink." The software entrepreneur who writes a program for people to do their taxes makes many millions of dollars, but accountants lose their jobs or find their wages inexorably squeezed.

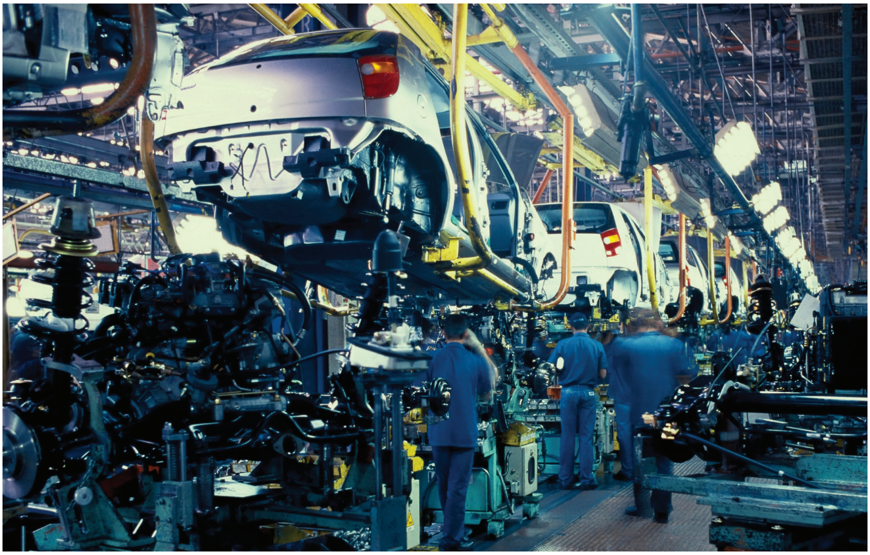

FIGURE 1-1 Gary Cowger described how the combination of advanced technologies with design and manufacturing processes that leveraged these technologies transformed the automobile assembly plant so that the same work could be done with one third of the people.

As Brynjolfsson and Andrew McAfee explain in their recent book, the economy is undergoing a profound restructuring.[2] Technology has been creating and destroying jobs for hundreds of years, but the pace is quickening, said Brynjolfsson, and the automation of jobs is outpacing the ability of entrepreneurs to create new jobs. "The technology is accelerating, and we think that the economic impacts are going to accelerate as well."

One possibility is that this trend will reverse and job growth eventually will strengthen. But Brynjolfsson cast doubt on this prospect. As an example, less than ten years ago, economists thought that truck drivers were one example of an occupation that could not be replaced by a computer.[3] Yet Google has succeeded in building an automated car

[2] Erik Brynjolfsson and Andrew McAfee. 2011. *Race Against the Machine: How the Digital Revolution Is Accelerating Innovation, Driving Productivity, and Irreversibly Transforming Employment and the Economy*. Digital Frontier Press.

[3] Frank Levy and Richard J. Murnane. 2004. *The New Division of Labor: How Computers Are Creating the Next Job Market*. Princeton, NJ: Princeton University Press.

BOX 1-2
The Past, Present, and Future of Manufacturing Work

To examine the future of work, Gary Cowger, chairman and CEO of GLC Ventures, LLC, who worked with General Motors for more than four decades, looked at how work has changed over that period. He began his career in 1965 at an automotive assembly plant in Kansas City. As an 18-year-old cooperative student, he worked for two years on the assembly line, hanging doors and bolting down seats. At that time, factories were the basic end of the industrial production process, where a pair of good hands was the main requirement.

Since then, the successful application of technology to manufacturing in the automobile industry has boosted productivity while reducing the number of jobs. The standard-sized factory in which Cowger worked employed around 5,000 people to make about 220,000 cars per year. Today, the same type of assembly plant employs approximately 1,500 people and makes about the same number of cars and trucks at a much higher quality level. In 1965, the factory included a roomful of people who went through "a forest worth of wood a month" printing paper manifests to track every single part that went into a car. On the factory floor were at least 120 classifications of workers, both skilled and nonskilled, which "was good for employment but not so good for productivity and flexibility."

The factory floor began to change in major ways during the 1980s. Company executives began to realize that early investments in computer technology were not paying off as they expected. Much more integration of the total production process was needed. According to Cowger, the company started to recognize that it wasn't just a technology problem but also a management problem.

Using tools such as computer-aided manufacturing and computer-aided design, managers began to break down the barriers between design, manufacturing engineering, and the factory floor. Design for manufacturability became an important discipline, especially after it became clear that an upfront investment of 5 percent of the overall cost of a product in its design, engineering, and development determines 70 to 75 percent of its total life cycle. "That was a huge shift for us in the way we had been addressing our product development process."

This integration of processes led to a much greater understanding of the principles of lean production and manufacturing engineering. As knowledge increased, the advent of common systems and global production systems tapped new sources of productivity. The use of high-speed computers, advanced robotics, better sensors, and new materials further added value. Today, every factory worker adds much more value than was the case in 1965. At the same time, the quality of the product has improved dramatically while the lives of workers have improved because they are now the center of the manufacturing system rather than a pair of hired hands.

These complex production processes could not be implemented everywhere in the world, Cowger observed, although many developing countries had a great desire and motivation to become the best and most efficient producers in the world, whether in Mexico, Eastern Europe, Brazil, India, or China. "The lessons that were so hard for us to learn in the developed countries were eagerly adopted by these developing countries." Because they could not afford all the high-technology equipment common in the developed world, they found innovative and cost-effective ways to implement the ideas embodied in those technologies. And this led to developed countries adopting these new low-cost, leaner approaches in their manufacturing systems as well.

What does all that mean for the future?, asked Cowger. Technology, and computer power in particular, will continue to drive change on the factory floor. Workers will have to be highly educated to use new technologies that will directly influence more and more jobs.

These new technologies will be used equally around the world. According to Cowger, the industry is now truly global and countries will not have a competitive advantage simply by monopolizing the use of a technology. Offices that have been shrinking will become more decentralized. An increasing number of knowledge workers will have the tools to become independent contractors selling their services without leaving their homes. Improvements on the factory floor will continue with the advent of smart sensors, and machines will continue to become more powerful. This will lead to more "lights-out factories" where processes are fully automated and require no human operators on the factory floor, just technicians to monitor the process. With all these developments, the rate of change in manufacturing will continue to increase. While the first learning cycle took more than a decade, "the learning cycle now is a matter of months."

that can drive through city streets, Brynjolfsson observed. Other jobs thought to be impervious to automation include those requiring both large stores of knowledge and judgment in accessing and sharing that knowledge. But the Watson computer program, which beat the world Jeopardy champion, is being adapted for medical diagnosis, finance, technical support, and many other jobs.

Usual approaches will not solve the problems caused by accelerating technology, Brynjolfsson said. “Big, creative solutions are necessary.”

He suggested that the key to solving the “struggles of the middle class” is to advance workforce skills and support entrepreneurship. People need to learn how to race with technology, not against it, he said. The best chess player in the world today is not a computer or a human but a team of humans and computers working together. In freestyle chess competitions, where teams of humans and computers compete, the winners tend not to be the teams with the most powerful computers or the best chess players. The winning teams are able to leverage the unique skills of humans and computers to work together. “That is a metaphor for what we can do going forward,” said Brynjolfsson: have people and technology work together in new ways to create value.

Brynjolfsson acknowledged that now is a terrible time, perhaps the worst time in history, to be competing with technology, but he added that “there is no better time to be a talented entrepreneur who can take innovations and scale them rapidly, digitally, and globally.” He predicted that manufacturing will surge in the United States because lower wages will not remain a competitive advantage in a world of steadily increasing computer power. At the same time, the most valuable jobs will be those in the design, development, and marketing parts of the product development cycle. Increasing employment in the United States therefore requires support for design and innovation, Brynjolfsson concluded.

WHAT IS VALUE? AND HOW DO WE MAKE IT?

Improving economic growth and employment requires more than the “spark of imagination,” said Larry Burns, former corporate vice president of R&D at General Motors. A new paradigm is needed for *making value* (Box 1-3), which he clarified is larger than “making things.” Making things (i.e., manufacturing) is often an important part, but making value requires an integrated system of understanding customers,[4] R&D,

[4] The term “customer” was used broadly throughout the workshop to refer to a person, group of people, or organization that makes use of a good or service.

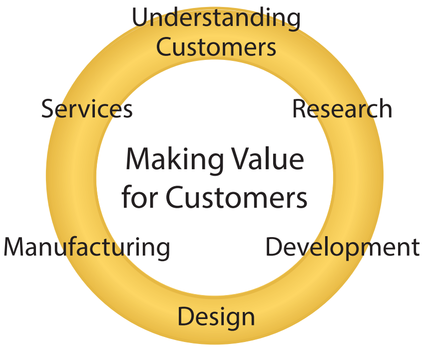

FIGURE 1-2 Making value for customers includes making things (manufacturing) as well as understanding customers, research, development, design, and the provision of services.

design, manufacturing, and the delivery of products and services (Figure 1-2). This integrated system requires the creation and delivery of value in the marketplace with a sustainable business model for the enterprise producing it, said Carlson. It is a customer-focused process of connecting important needs with new knowledge.

From a customer's perspective, value ranges from the strictly utilitarian to the emotional. As an example, Carlson contrasted Nokia, which builds low-cost mobile phones, to Apple, which has created products that have emotional appeal to customers. As a result, Apple's market capitalization is now almost $600 billion, while Nokia's is down to $15 billion and declining. "You can't be on the bottom of the stack any more. You have to work your way up the stack if you want to thrive and be successful."

Value comes in many forms, Carlson said. It can include the design of a beautiful chair, the invention of the computer mouse, or the development of microcredit, a financing service designed to support entrepreneurship and alleviate poverty by extending very small loans to impoverished borrowers.

As examples of two people who understood deeply how to make value, Carlson cited Akio Morita, the cofounder of Sony Corporation, and Steve Jobs, the cofounder of Apple, Inc. Both recognized multibillion-dollar opportunities in the "white spaces" of audiovisual communications development across two dimensions of customer value: quality and convenience (Figure 1-3). In the dimension of quality, AM radio

BOX 1-3
Making Value in America

"High-value integrated innovation, design, manufacturing, and service is the primary path forward for the United States to prosper."
– Panos Papalambros

In discussions of the concept at the heart of the workshop—making value through the integration of manufacturing, design, and innovation—participants added a fourth major component: service. These four aspects are both distinct and interconnected, as represented by the pyramid shown in Figure B1-3.1. Panos Papalambros explained that services—such as software upgrades, information gathered about a product, or maintenance and replacement—are important to include because they add value to a product after it is released. Indeed, services are often associated with a product throughout its life cycle, from marketing to design to supply-chain management services.

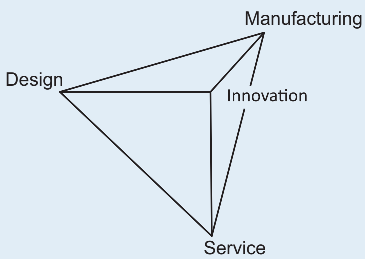

FIGURE B1-3.1 Innovation, design, manufacturing, and service are tightly linked with each other, forming an integrated whole.

gave way to FM radio, and black and white TV led to color, high-definition, and now superresolution and three-dimensional TV. In the dimension of convenience, Morita recognized the immense value in portable radios and created a multibillion-dollar company based on that insight. He then invented the Walkman, presaging a world of rich, multimedia personal electronic devices. Steve Jobs furthered this trend with the iPod, a device so convenient that it now can be put on a keychain. In the process, Jobs created a multimillion-dollar business out of almost nothing because he understood the value of convenience to customers.

Several of the breakout groups explored the concept of making

Larry Burns challenged the participants to consider whether integration is necessary to the future prosperity of the United States. Several participants voiced support for Papalambros' statement quoted above. Chad Syverson articulated the arguments supporting why this path may be necessary rather than an economy based on "pure services." First, we may lose certain types of very high-level human capital—a large percentage of scientists and engineers in the United States are employed by the manufacturing sector. Second, a manufacturing base may be imperative for national defense. Finally, there is a diversification argument: "you don't want all your eggs in one economic sector basket."

One breakout group explored these arguments by trying to identify a first-world country that does not have a significant manufacturing sector. Hong Kong and Iceland were suggested. Jung-Hoon Chun, director of the Laboratory for Manufacturing and Productivity and professor of mechanical engineering at the Massachusetts Institute of Technology, pointed out that these countries worry about their lack of a manufacturing sector. He and his colleagues work with the Hong Kong government, where he said officials worry that the country relies too much on the finance sector. They would like to build up other parts of the economy, Chun said, but are finding it difficult because, although they have research universities, many of their students go abroad to find work once they graduate. It is difficult for the country to retain its talent.

value. According to one group, making value requires understanding the value that people receive from products, explained Panos Papalambros, executive director of interdisciplinary and professional engineering, Donald C. Graham Professor of Engineering, and professor of mechanical engineering at the University of Michigan. To illustrate, he held up two very different products: an iPhone and a bottle of water. The first, he explained, provides convenience, access to rapid information, connectivity, and entertainment; the second, consistency of taste, quality, safety, and convenience. Each has an impact on a person's lifestyle, which is critical for adding value, Papalambros said; a high-value

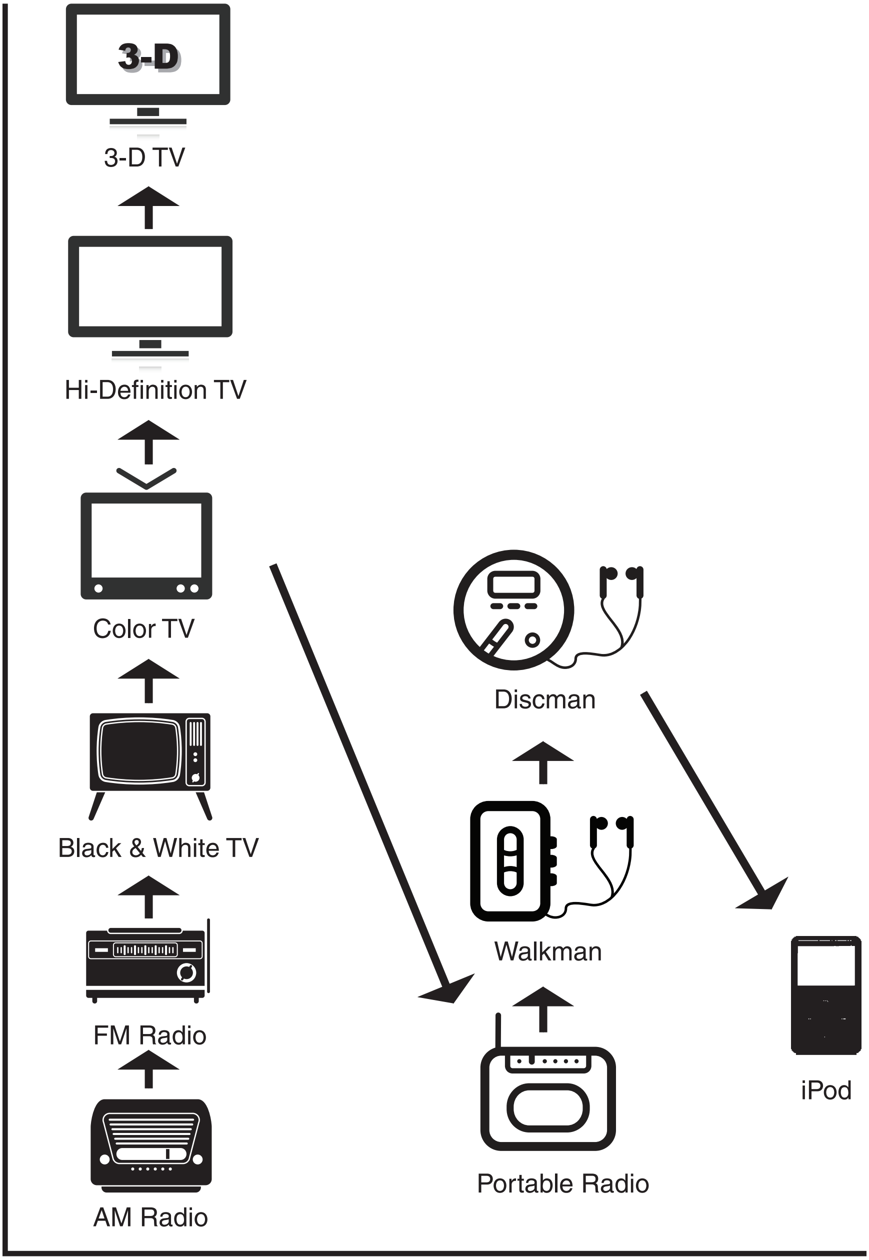

FIGURE 1-3 Curt Carlson mapped the timeline of product developments in the audio-visual communications industry along two dimensions of customer value: quality and convenience. "Every white space [on this chart] is another multibillion-dollar business for a company that can see them and take advantage of them."

product "should make your life easier." He added that, even if people did not know that they wanted a product, if it adds value, once they have it, they want it and need it.

Papalambros also discussed the importance of services, such as those provided by software and interconnectivity, to understand the value a person gets from a manufactured product. Too often, a manufactured product is thought of as something that is simply produced and delivered. But value comes from how a product is used, said Papalambros, and it can increase over time if the product is designed with that characteristic in mind. A smart phone is an obvious example, because the addition of apps can increase the value of the phone. There are examples from many other industries as well. For instance, a drug designed for one disease may turn out to be a useful treatment for other diseases as information emerges about the drug and its side effects. This increases the value of the drug not from original thinking but from information analysis, said Papalambros. Another example is a navigation system for a car that can produce information useful in the design of future models. In general, any product that has a software component that can be reprogrammed or an ecosystem that can gather information about itself and its uses can improve over time, Papalambros said.

Rebecca Taylor, senior vice president of the National Center for Manufacturing Sciences (NCMS), described the process of increasing the value of existing products. The entire life cycle of a product, from the moment it is delivered to the moment it is no longer needed, can produce value, she said. For example, Rolls-Royce not only produces aircraft engines but also provides performance monitoring, maintenance, and support services throughout the product's life. Close monitoring of the engines enables Rolls-Royce to predict when they will need maintenance, allowing them to efficiently schedule repairs, as well as informing future engine designs. Both incremental and radical innovation is important for value creation, said Taylor. The internal combustion engine, for example, is 100 years old but keeps getting better. Meanwhile, radical innovations can not only transform an existing product but create new products that transcend the need for an existing product.

Ken Gabriel, acting director of the Defense Advanced Research Projects Agency (DARPA), pointed out that understanding production is crucial to innovation. "To innovate, you must make." It is a mistake, he said, to think that effective innovation means coming up with a great idea and then passing it to someone else to develop and manufacture a product. A major lesson of DARPA's history is that this process is not

BOX 1-4
Spotlight on Electronics: Linking Design and Production

When Jonathan Rubinstein, former executive chairman and CEO of Palm, Inc., and a former executive at Apple, took his first job after college with Hewlett-Packard in Fort Collins, Colorado, his goal was to design and build computers, as he had been doing on his own throughout his student years. But the company did not have any openings to build hardware, so instead he went to work in manufacturing engineering. At that time there was a very tight connection between manufacturing and R&D at Hewlett-Packard. "It was a remarkable experience," he said, that taught him lessons "I would not have normally gotten through our educational system."

Today, product development and manufacturing still need to be tightly coupled for a product to succeed, said Rubinstein. When Apple was floundering, this approach got it back on track. The iMac was one of the first examples. At that time, the typical design cycle at Apple took two to three years. "We did the iMac in 11 months," said Rubinstein, "and in doing so we established a whole new process for developing products at Apple."

Apple applies the same approach to the development and use of materials. For example, the Cube computer was made of clear plastic in a single molded piece. Although the product was a commercial failure, "we learned more about how to do large-scale molding without lines or anything else in it from that product, which then evolved

linear. Idea generation, creativity, technology, and manufacturing all feed on each other and drive better ideas, better manufacturing, and better technology developments. "It is in the making, the doing, that creativity and genius are actually driven," said Gabriel.

A major focus of the workshop was the proposition that the process of making value requires an integrated system of innovation, design, manufacturing, and services (Box 1-3). "It is the integrated process that leads to success," Carlson said. "If you put your innovation hat on, you don't think of them as separate things. You think of them as essential, necessary pieces of the puzzle that all have to fit together."

Integration of the entire process of making value is happening more and more, said Theresa Kotanchek, Dow's Global Technology Director into all the other products at Apple." Similarly, Apple has developed whole new manufacturing processes to meet design criteria, such as facilities to do high-volume plating for iPods.

The clue to product development is to recognize a need in the marketplace, innovate quickly, and then iterate, said Rubinstein. This observation also applies to the construction of new processes and facilities. A plant in China to do the plating for the iPod Nano went from an empty field to a functioning facility in 11 months. "High risk? Yes. But also high reward. And that comes down to the speed of development and the speed of innovation."

But high-tech manufacturing of many consumer electronic products in the United States is not practical, said Rubinstein. America does not have enough tooling engineers to do large-scale electronics manufacturing, whereas China has "armies of people." And the problem is not just tooling engineers. The United States does not have enough "manufacturing engineers, process engineers—a variety of types of engineering." Even if US colleges and universities were to produce more engineers in general, these kinds of engineers would be in short supply.

Products are not just manufactured in China, Rubinstein reminded the workshop participants. Design teams in the United States collaborate closely with manufacturing teams in China, with travel in both directions, throughout the life cycle of a product. The idea that designers create a product and heave it over the wall to manufacturing "is not how you get fast-paced, high-innovation kinds of products."

for Asia Pacific and India-Middle East-Africa. Dow's advanced materials team includes people in the United States and in China literally working side-by-side with the designers of the companies we supply, she said. The people that have a leading influence over the value that is embodied in a product must all work closely together so that the entire supply chain has ownership over the product being created.

Don Norman, cofounder of the Nielsen Norman Group and IDEO Fellow,[5] raised the additional point that the integrated process of making value means that customers are increasingly engaged. The model of

[5] The IDEO.org Fellowship Program supports design leaders of the future for 12 months to work on social innovation projects (https://www.ideo.org/fellows).

one group of people designing and making things that another group of people uses is out of date, he said. Users modify products they have purchased and then sell them to others, thereby creating value in an iterative loop. For example, Harley Davison motorcycle owners are famous for altering their motorcycles with custom parts and paint. The ability of individuals to design and produce is becoming easier. Individuals can now easily produce, share, and sell books with the rise of self-publishing. The same capabilities are emerging in manufacturing. With new technologies such as low-cost three-dimensional printers, everyone can be engaged in continual design, manufacturing, and innovation, said Norman. "The new model is that we are all producers, we are all designers."

DOES INTEGRATION REQUIRE COLOCATION?

Does integration of the value chain require colocation of research, design, and manufacturing activities? A couple of breakout groups explored this question.

The importance of geographic colocation depends on the product, the production process, and the industry, said Chad Syverson, professor of economics at the University of Chicago Booth School of Business, who reported back from one of the groups. In general, colocation is more important when the production process is innovative, because process innovation requires learning by doing and trying to figure things out. For example, if the production process involves advanced materials, a new production process is often required for each new product, so close connections are needed between product design, process design, and production. Conversely, colocation is less important if a product is being made through a set of mature, codified processes, even if the product design is very innovative. For example, many semiconductors used in cell phones and computers are designed by companies that have outsourced the fabrication of these devices.

Improved communications technologies make it easier to operate at a distance than in the past, Syverson said. On the other hand, production technologies that are labor or capital intensive may create a greater incentive for colocation. There is no obvious trend one way or the other, Syverson said.

Even when manufacturing can be located in a different place from other parts of the value chain, it is important for designers and innovators to be engaged in the manufacturing process (Box 1-4). It is difficult to imagine how individuals can innovate on processes, materials, and products if they do not have the chance to see and interact with the manufacturing process, said Bud Peterson, president of the Georgia Institute of Technology. Ken Gabriel gave an example from his experience at Akustica, a technology company he cofounded, illustrating how physical proximity can be important even with advanced communications technologies. A performance issue arose with the production of microphones, he explained, and the engineering team in Pittsburgh worked with the manufacturing team in China for weeks, via web-based conference calls and pictures of the production process, to try to find the problem. Finally, the company sent a staff member to China, Gabriel said, and in 30 minutes the problem was identified.

Willy Shih, professor of management practice at Harvard Business School, observed that many companies have replaced geographic colocation with frequent air travel. In the 1980s, colocation was much more common. But once China opened up its economy, the production costs were so low, Shih said, that "managers threw that out the window and said, 'We will fill the sky with planes because it is cheaper.'" It's possible that colocation will again become more important.

2

Building the Ecosystem for Making Value

Workshop discussions focused on the importance of making value by not only integrating innovation, design, manufacturing, and services but also aligning them to address the complete experiences of their customers. Such steps can improve economic growth, environmental sustainability, and quality of life in the United States and provide employment for workers with the appropriate skills.

However, when asked whether these practices are currently being implemented, participants indicated that while a few high-performing companies have adopted them, the vast majority have not. Rubinstein posited that the reason some companies are not performing well is that they haven't adopted these practices.

What barriers in the United States may prevent the creation and delivery of value? Multiple participants cited the importance of four factors: human capital, business practices, government services, and infrastructure. They also noted that business, all levels of education, and all levels of government have important roles to play, both separately and in collaboration, in strengthening these four central pieces of the ecosystem for making value.

HUMAN CAPITAL

The fundamentals for success in an innovation economy, Carlson said, are the best team of people, a transformative product that addresses an important need, a flexible process for value creation, and a supporting ecosystem.

Having the best team requires supportive immigration and education systems, Carlson continued. Immigrants are essential for America's innovation leadership. "You take all of the foreign-born people out of Silicon Valley, it is just another pleasant place in California; it is not Silicon Valley." This is the case all across America: 40 percent of Fortune 500 companies were founded by immigrants or their children. "The H1B visa is one of the most powerful forces we have in America. You can call it America's genius card." If Albert Einstein wanted to enter America today, he would have to get in line, Carlson said, and he might not get in.

In addition, more than half of the science and technology graduate students in US universities are from overseas, and in some schools the percentage is close to 100 percent. According to Carlson, the US government should give each of these students a green card upon graduation.

Carlson also discussed the glaring mismatch between the limitless opportunities in today's world and the limitations of K–12 education in the United States. Good jobs are still being created in America, but many students do not have the skills needed to do those jobs. Despite substantial increases in funding for K–12 education, outcomes have improved little, Carlson said; in Detroit, for example, less than 25 percent of boys graduate from high school.

But Carlson also cited reasons for hope. Innovations bubbling up in the United States, such as the Khan Academy, have the potential to transform US education. American educators are learning from successful education systems how to build both excellence and a focus on innovation into school systems. Aspects of successful programs in the United States (Box 2-1) and in other countries, such as Finland and Singapore, can be emulated. As examples, Carlson cited the Institute of Design at Stanford University[1] and the world's first "innovation university" in Finland,[2] where students study innovation in a project-based curriculum all four years (Figure 2-1).

He also described a program in Palo Alto called the Girls Middle

---

[1] The Hasso Plattner Institute of Design (called the "d.school") is a hub for students in engineering, the arts, medicine, business, law, the humanities, social sciences, and education to collaborate and take classes together. Courses focus on project-based learning where students from very different backgrounds work together to develop innovative, human-centered solutions to real-world challenges. Online at *dschool.stanford.edu/*.

[2] Aalto University was created through the merger of the Helsinki School of Economics, the University of Art and Design Helsinki, and the Helsinki University of Technology. The University encourages multidisciplinary education and research with many project-based courses focused on design and product development in collaboration with Finnish companies. Online at *www.aalto.fi/en/*.

FIGURE 2-1 Curt Carlson highlighted the Institute of Design at Stanford University and Aalto University, which both focus on project-based learning where students seek solutions to real-world challenges, as successful examples of educational programs for innovation.

School,[3] where seventh-grade girls go through a two-day "boot camp" to learn how to form a company. They write a business plan in teams of three to four, pitch their ideas to panels of venture capitalists from Silicon Valley, and receive awards of $100 or so to fund their ideas. They run their companies for a year, then pay back their venture capitalists with interest and split the remaining proceeds among the team members. They learn that innovation is a skill, and they master that skill, said Carlson. "Imagine if we had an education system that was teaching this from kindergarten through college through graduate school."

Michael Molnar, chief manufacturing officer at the National Institute of Standards and Technology, emphasized the need for quick action to improve the education system in the United States, given the urgency

[3] The Girls' Middle School (GMS) is a school for sixth to eighth grade girls that focuses on project-based learning and offers courses in entrepreneurial studies, engineering, and computer science in addition to subjects in math, science, and art. Online at *www.girlsms.org/*.

of the problem. Teamwork and learning by doing have always been important in education, he said; now, people need to learn entrepreneurship, and at all levels of education—grade school, high school, community colleges, universities, and lifelong learning. Students need to learn about effective teamwork, systems thinking, and integration across technologies and multiple disciplines. They need to learn how to conceive and create products that have value. Every year of college should have a course in product design and manufacturing that involves building a physical prototype, Molnar said.

Industry, educational institutions, and government all have roles to play in advancing workforce skills. Industry needs to take the lead in providing opportunities for experiential learning, said Molnar, not just for employees but also for high school students, college students, and the larger community. These should be year-round opportunities for people to come into a company and rotate through different roles, he said.

Several participants also suggested possible actions to teach Americans the skills needed to create products and services that have value. Matt Sakey, an expert in interactive learning, proposed lengthening the school year to allow more time for education. He also called for an end to the stigma against vocational education, which is hurting the US economy by discouraging students from pursuing these useful and needed skills.

Papalambros made the case for incentives in academia to encourage hands-on education. Universities introduce the fundamentals of physics, biology, chemistry, and other disciplines to students early in their undergraduate education, but many do not teach the fundamentals of innovation, design, or manufacturing at a comparably early stage. Furthermore, university faculty who teach design and manufacturing generally find it harder to get promoted, Papalambros said. Multiple participants suggested that one way to promote research and teaching in these types of fields would be to create a National Engineering Foundation to complement the National Science Foundation (NSF). They also proposed that NSF make integrated innovation, design, manufacturing, and services a priority, in part by creating prestigious fellowships and research grants to encourage research and curriculum development related to this area.

Rebecca Taylor pointed out that models of learning should change to embrace interactive and online learning. Children who have grown up immersed in an electronic world do not learn well from lecturing, she said, which means that the curriculum needs to become much more

BOX 2-1
Creating Human Capital:
Manufacturing, Design, and Innovation Education at Georgia Tech

Universities produce what Bud Peterson, president of the Georgia Institute of Technology, called "the most important facet of the innovation ecosystem": the engineers, scientists, and other leaders who can maintain the nation's preeminence in advanced manufacturing. This leadership can help overcome the advantage of low labor costs elsewhere in the world.

Georgia Tech and other institutions have been developing an initiative to inspire the next generation of manufacturers in the United States based on the Changing the Conversation campaign led by the National Academy of Engineering. With a grant from DARPA, Georgia Tech is offering manufacturing education programs for high school students around the country, encouraging them to use the latest technology to design and build items such as wind turbine blades, mobile ground and air robots, and electric cars. New technologies such as 3D printers are being used to attract a new generation of young people to manufacturing. Students from all over the United States and the world can connect through social networks to innovate, create, and design. "We are trying to change the perception of manufacturing from dumb, dirty, and dying to…creative, innovative, and exciting."

interactive. Some universities are extending interactive learning to the online world, where hundreds of thousands of students can learn from a single course.

BUSINESS PRACTICES

Every CEO acknowledges that the world is moving faster and that companies need to do a better job at innovation, said Carlson. But when he goes into an organization and asks people to describe their innovation systems, he usually gets blank looks. Businesses need to think about their work in a new, more fundamental way, one based on the principles of innovation. A critical approach, for example, is to identify a transfor-

Peterson also described a club called the Georgia Tech Makers Club, which has 50 volunteer undergraduate students who train other students and offer lessons in prototyping, manufacturing processes, advanced manufacturing approaches, and other topics related to manufacturing. More than 500 students are involved with the club every semester, and it is used in 35 classes.

Georgia Tech emphasizes innovation in both its curriculum and teaching approaches. For example, under a program called Adventure Products, teams of students prepare a three-minute video about an idea, make a three-minute presentation before a panel of judges, and then answer questions for three minutes. The first prize is $15,000, the second prize $10,000, and the third prize $5,000, each with a commitment from the technology licensing office to help the teams commercialize the products they develop. In 2011, more than 400 students and teams competed for prizes, and for each of the past three years, the first prize winner's product was commercially available before the next year's competition. "We are trying to inspire students to understand that innovation can and should be a critical part of their thought process and their educational program."

Finally, Peterson described the need for partnerships to strengthen the manufacturing ecosystem. Just as business schools often partner with businesses and bring in "professors of practice," Georgia Tech brings in professors of practice to show students the opportunities in business and manufacturing and the importance of innovation in the manufacturing ecosystem.

mative product that addresses a major need. At present, he said, very few companies have a process to connect important needs with new knowledge in a compelling, sustainable way.

Carlson also focused on the early stages of the product design cycle. Value creation starts at the beginning of this cycle, and that is where many mistakes are made. For example, innovators can spend a lot of time and money early in product design without identifying a worthwhile opportunity. In addition, information technology is speeding up and compressing the product development cycle, which means that product development needs to move much faster to get a product into the marketplace.

Companies need to develop a standardized process for continuous value creation, Carlson proposed. One way to think about it is as a playbook for staff, he said. As an example, he described SRI's process of value creation (Box 2-2). Companies need to have a family of shared concepts and language to talk about innovation, to create customer value, and to iterate quickly.

The United States has revamped its innovation system before, Carlson noted. Total quality management, as developed by Edward Deming and implemented initially in Japan, transformed production processes and is now used throughout the world. A similar revolution is needed today, Carlson said.

Taylor explained how a culture of risk aversion in many companies impedes innovation. Many untapped ideas and technologies await development, she said, because companies will not take on the risks of developing new innovations (see Box 2-3). She cited three major changes that are needed in organizational culture to promote innovation. First, accept failures as necessary steps in order to get to the next big success. Second, promote out-of-the-box thinking, so that companies do not devote all their efforts to doing what they have done in the past. Third, understand the complete experience customers have with your product from the moment they first want it to the moment they no longer need it. How many automotive CEOs have ever haggled over price at a dealership, Taylor asked.

GOVERNMENT SERVICES

There was considerable discussion about how federal, state, and local government services could be changed to enable innovation and entrepreneurship. Three major themes emerged: the speed of delivering government services, the consistency of government policies, and taxes and subsidies.

One area that would benefit from acceleration is the process of verifying regulatory compliance of products and manufacturing facilities, according to participants. Rubinstein noted that, when he worked on developing the iPod Nano at Apple, the production factory, which produced millions of units, was built in China in about seven months. Just getting the permits to build a factory in the United States would be impossible in that amount of time, he said, although he added that regulations in the United States do have advantages: Americans enjoy clean water and air. But the lengthy permitting processes make it impossible to innovate quickly.

BOX 2-2
SRI's Value Creation Process

SRI uses a method to develop a quantitative value proposition that it refers to as NABC: identify an important customer *need*, meet that need with a unique and compelling *approach*, and provide superior *benefits* when compared with the *competition*.

In its work with executives, SRI asks them to write down a value proposition, get input from colleagues, listen to prospective customers and partners, and then iterate the proposition based on this process (Figure B2-2.1). SRI has thus been able to create and spin off two or three companies a year. For example, it incubated the Siri company (eventually acquired by Apple) for four years before spinning it off.

"The things I just talked about seem easy but they are not," said Carlson. "They are really hard to do. I have done hundreds of these value propositions. I have never gotten one right the first time, the 10th time, the 30th time, the 50th time. It takes lots of iterations, [and] you want to go as fast as you can."

FIGURE B2-2.1 SRI International developed a method for innovation that emphasizes understanding important needs, developing a compelling value proposition, and getting rapid feedback from colleagues and partners.

Dordick talked about the need to speed up regulatory compliance procedures in the context of pharmaceuticals (Figure 2-2). Pharmaceutical companies are required to do some tests that may not be predictive, such as preclinical tests on animals that end up not predicting safety for humans. Shortening the regulatory process will become even more important with the emergence of personalized medicine. To transform the pharmaceutical industry from producing large volumes of a relatively small number of products to small volumes of a large number of products, regulatory approaches have to be dramatically shortened, Dordick said.

Dordick agreed with Rubinstein that regulations for health and safety are not a bad thing. But he contended that by leveraging information and developments in biotechnology, the same or better level of safety can be achieved in less time. "We can and should have a much greater level of discussion about what kind of changes are needed [for drug approval], and the public has to be involved in this."

FIGURE 2-2 John Dordick explained how personalized medicine could transform the pharmaceutical industry, but in order to do so, regulatory procedures for drug approval have to be dramatically shortened.

Carlson suggested that the time efficiency of government services could be improved by increasing transparency and tracking performance metrics. As an example, he cited the city of St. Petersburg, Florida, which publishes tracking metrics associated with city services on the web. "How long does it take to repair a sidewalk? It is on the web: it used to be a year and a half, it is now down to a couple of weeks."

In addition to the speed of government services, participants cited the need for consistent policies to support and enhance value creation. The 50 states have many different regulations, which makes it very difficult for manufacturers, Taylor explained. A company can go through the complete permitting process to build a facility in Kentucky, and then have to start from square one when it wants to build a similar facility in Nevada.

In addition, programs like R&D credits that are implemented one year and discontinued the next are of no use to a company that is looking at doing something for the next 10 to 20 years. "Unless [a policy] is there and in place for a reasonable length of time, we might as well not do it," said Carlson. "It just adds more confusion."

A number of participants also pointed to the importance of supporting entrepreneurship by focusing on new businesses instead of only small businesses, most of which have fewer than 10 employees and are not likely to grow substantially. Policies need to focus instead on new companies that can scale, Carlson said, since new companies have created most of the jobs in America over the last 20 years.[4]

Syverson explained that understanding the interactions of the many types of policies can improve the consistency and clarity of those that affect US ability to make value. There should be some thought and coordination by the government about how policies interact with one another, he said. As it is, piecemeal policymaking pulls innovation, manufacturing, and entrepreneurship in different directions. "When you add it up you have no idea what you are getting when they all interact."

The government should seek to create a competitive ecosystem in all policy areas where it has an influence, according to the participants in one breakout session. The United States would not necessarily have to have the lowest tax rate or the highest subsidies, but by seeking to be

---

[4] See Haltiwanger, J.C., R. S. Jarmin, and J. Miranda. 2011. "Who creates jobs? Small vs. large vs. young." NBER Working Paper No. 16300, which shows that companies less than 10 years old accounted for the majority of job creation from 1975-2005, and that once company age is controlled for, there is no systematic relationship between company size and job growth.

BOX 2-3
Different Collaborative Models for Innovation in Large and Small Companies

Dawn White, founder, president, and CTO of Accio Energy, said that she has experience as both an "intra-preneur" and an entrepreneur. As an intra-preneur at Ford, she likened the experience to blowing up a balloon in a vat of concrete with a tank of compressed air. Plenty of resources are available, she explained, but there is little room for innovation, so good ideas tend not to get passed up the ladder toward implementation. Companies are skilled at process leadership and successful launches, she said, but they tend to avoid execution risk.

In contrast, being an entrepreneur is like blowing up a balloon in outer space. There is no resistance, but not much oxygen either. Because of that lack of resources, start-up companies rely on their local ecosystems much more to develop successful innovation and commercialization models.

A classic innovation and commercialization model draws on venture capital to test the technical and market potential of an innovation. Venture capitalists also help small companies build teams to launch a product, thus managing execution risk. This model tends to work best in places like Silicon Valley, where the ecosystem of people, processes, and financing is well developed. But it is not as good in other parts of the country, such as Southeast Michigan, where White's company is located, because that type of ecosystem doesn't exist.

An alternative model is the collaboration or acquisition model.

competitive in each, the net effect of government would be to advance rather than impede business.

INFRASTRUCTURE FOR INFORMATION AND TECHNOLOGY DEVELOPMENT

A major barrier to the creation of value is a lack of infrastructure to support advanced information collection and analysis, according to participants, who called for opportunities to leverage information in

Collaborating with larger companies can reduce technical or market risks to acceptable levels by leveraging existing capabilities in product development, manufacturing technology, and distribution. This is the model White has adopted, because her company is located near many large automotive companies with some of the "world's best people for scaling up manufacturing technology and doing it at very low cost." Furthermore, many underused people, plants, and equipment are in the region. "We focused our technology and business model around something we can do right where we are." Such collaborations can be essential in crossing the chasm from a good idea to a good product.

White described several programs designed to help build collaborations between large companies and start-ups. Siemens has a program to bring in small companies that will be ready to enter the market with a product in several years. A team of people helps organize a project with one of Siemens' business units. "They can assess you, you can assess them, and they can see if some of these technologies will fit." In Michigan, General Electric has opened a facility to develop advanced manufacturing technologies and is pursuing collaborations with small companies interested in using these technologies.

White also has collaborated with the National Center for Manufacturing Sciences while working with four companies on different products and markets. "In every one of them, we had productive collaborations between large companies and small companies. Sometimes I was on the large company end, sometimes on the small. But everybody benefited and moved technologies forward."

industries ranging from electronics to automobiles to pharmaceuticals (Figure 2-3).

Papalambros cited the importance of gathering information about products and their use to improve performance, but noted that the lack of privacy standards is a concern that prevents some companies from pursuing these opportunities. In an era when vast amounts of information are available, he said, privacy is clearly an issue that needs to be considered.

Many of the ways to make value involve leveraging information. "Information itself is changing," Sakey observed, and the ways it is dis-

FIGURE 2-3 Several participants pointed out that many future opportunities to make value involve leveraging information in industries ranging from electronics to automobiles to pharmaceuticals.

tributed, analyzed, understood, and protected all have to change as well. Information needs to be audited, assessed, and validated by impartial and trusted individuals, and it needs to be more transparent, so that databases, websites, and tools are available for the use of manufacturers and organizations from other sectors.

Throughout the workshop participants emphasized the importance of an infrastructure to support technology development, and identified issues associated with the development of research ideas to commercialization.

Dordick discussed the challenges of negotiating intellectual property (IP) rights in collaborations between companies and universities. There is such a tremendous concern about developing the next big thing that nobody wants to talk to each other, he said; as a result, new inventions that come out of universities often are not transferred to companies. “IP and other things stand in the way.” Companies, especially pharmaceutical companies, need to find a way to collaborate with universities, because such collaborations will benefit everyone.

Multiple participants cited the need for investments to support research and development in certain high-priority fields. Stephanie Shipp, a researcher at the Science and Technology Policy Institute, added that a long-term vision is needed to identify these priorities. How can the critical elements of infrastructure be identified? What phases of innovation—from research to commercialization—should receive public funding? One option Shipp suggested is investing in "platform technologies" such as energy storage or biomanufacturing to avoid "picking winners and losers" from specific technologies in these fields. As an alternative, another participant suggested focusing on challenges, such as environmental sustainability (Box 2-4), energy independence, and improved health, instead of technological solutions. As Shipp said, "What is our Sputnik moment for the next 10, 20, 30, 50 years?"

LEAPFROGGING TO THE NEXT GENERATION

Several participants pointed out that the United States is unlikely to regain the manufacturing of particular products that now are made elsewhere. But it has a prime opportunity, through an emphasis on value creation, to leapfrog to leadership in the next generation of integrated innovation, design, manufacturing, and services. We have to look to where things are going, Rubinstein said, and make sure that we have the capabilities and the skills in this country to deliver the next generation of products and services.

Taylor suggested that the United States may have a competitive advantage in the integration of innovation, design, manufacturing, and services because of its relative strength in taking a systems perspective. US science and technology have spurred invention for decades, and successful US companies have leveraged these inventions to create new systems that meet customer needs and wants. For example, companies such as Apple and Procter & Gamble excel in creating innovative products by combining existing technologies in new ways with effective and appealing designs. The task ahead, Taylor suggested, is to build on these strengths and promote an integrated approach to value creation.

Today's world presents immense opportunities, Carlson said. "But it is a new game, and we need to get serious about playing the game to win here in America if we want to keep America the great country that we know it is."

BOX 2-4
Manufacturing for Sustainability

Sustainability is the next great opportunity for motivating students to pursue science, technology, engineering, and mathematics education, said Jay Golden, director of the Center for Sustainability and Commerce at Duke University. Furthermore, sustainability has a direct link to manufacturing, since many sustainability issues involve the design and making of things.

Golden cited six drivers of sustainability issues. The first is the growth in world population, from 7 billion people today to a projection of more than 9 billion in the year 2050 and more than 10 billion by 2100. Approximately 37 percent of the world's population lives in China and India, and by 2021 India will overtake China as the most populous country in the world.

The second driving force is the rapid urbanization of the world's population. In 2010 the world's urban population surpassed the rural population, and by 2050 it is projected to be twice as large as the rural population. Over the next two generations, said Golden, the equivalent of a thousand great cities with populations of more than five million will be built—an average of 20 each year.

The third driver is the expansion of the middle class—from less than one-third of the world's population to more than one-half. As incomes grow, people will consume more and place greater demands on the world's resources.

The extraction of resources is the fourth driver. The consumption of biomass, minerals, metals, and fossil fuels are all projected to rise in future decades. One consequence of this projected increase, according to Golden, is a rapid rise in international land acquisitions by foreign parties. "The equivalent of half of Western Europe has been acquired in Africa alone since 2000."

The fifth driver consists of governmental laws and regulations to promote sustainability. For example, US Executive Order 13514 requires that 95 percent of all applicable new contract actions for products and services advance sustainable acquisition. Similar provisions are appearing in countries around the world to quantify and reduce resource impacts.

Finally, the private sector realizes that it needs to address sustainability issues as part of the issues associated with the goods and services it sells.

Sustainability Indexes

A variety of efforts are under way to measure and report on the sustainability of products, Golden said. For example, Nike has led the development of a Materials Sustainability Index that encompasses about 40,000 different materials. International teams of researchers have done technical reviews of quantification methods to evaluate the sustainability of products throughout the supply chain. Innovators and designers can use this information to build sustainability into products throughout their life cycle. This information also can be used to evaluate suppliers of products no matter where they are located. “It is a common language, a common set of metrics and indicators, which everybody has to aspire to,” said Golden.

Much more can be done to develop and disseminate information. Golden called for the establishment of a National Sustainability Computation Center to support industry. Such a center could gather, analyze, and distribute data through a variety of public sector and private sector networks while also supporting education and outreach. It could address such issues as food security, ecosystem services, employment, shelter, energy, water scarcity, and national security.

Appendix A

Workshop Agenda

Making Value: Integrating Manufacturing, Design, and Innovation to Thrive in the Changing Global Economy

June 11–12, 2012
Venable LLC Conference Center
575 7th Street NW
Washington, DC

June 11, 2012

8:00 a.m. Welcome and Opening Remarks
Lawrence D. Burns, Professor of Engineering Practice, University of Michigan; Chair, NAE Committee on Manufacturing, Design, and Innovation
Charles M. Vest, President, National Academy of Engineering

8:15 a.m. Opening Keynote
Curtis R. Carlson, CEO, SRI International

8:45 a.m. *Q&A*

9:00 a.m. **1st PANEL**
The Changing Nature of Manufacturing, Design, and Innovation

Moderator:
Louis Rassey, Principal, McKinsey & Company

Panelists:
Jonathan J. Rubinstein, Former Executive Chairman and CEO of Palm, Inc.
Jonathan Dordick, Director, Center for Biotechnology & Interdisciplinary Studies, Rensselaer Polytechnic Institute

9:30 a.m. *Q&A*

10:00 a.m. *Break*

10:15 a.m. **2nd PANEL**
The Future of Work

Moderator:
Laura Steinberg, Dean, L.C. Smith College of Engineering and Computer Science, Syracuse University

Panelists:
Gary Cowger, Retired Group Vice President, Manufacturing and Labor, General Motors Corporation
Erik Brynjolfsson, Director of the Center for Digital Business and Schussel Family Professor, MIT Sloan School of Management

10:50 a.m. *Q&A*

11:20 a.m. **3rd PANEL**
Building the Ecosystem for the Future of Manufacturing, Design and Innovation

Moderator:
Willy Shih, Professor of Management Practice, Harvard Business School

Panelists:
Dawn White, President and CTO, Accio Energy
G.P. "Bud" Peterson, President of the Georgia Institute of Technology
Kaigham Gabriel, Acting Director, Defense Advanced Research Projects Agency

11:50 a.m. *Q&A*

12:30 p.m. ***Luncheon***

Luncheon Keynote
Jay Golden, Director, Duke Center for Sustainability & Commerce

1:30 p.m. PARALLEL BREAKOUT GROUPS
Parallel discussions assessing the role of key factors on the M/D/I ecosystem, the ability for the U.S. to capture the value of this ecosystem, and how the future direction of M/D/I may change these relationships

Group A
The Relationship of Making Things and Making Value

Group B
Productivity, Innovation, and Business Practices

Group C
The Role of Geography in Creating and Capturing Value

Group D
Enabling the Workforce for the Future of M/D/I

Group E
Building the Institutional Structure for M/D/I

Group F
Opportunities for Making Value

3:30 p.m. *Break*

3:45 p.m. ***Breakout Group Summary Remarks***

Closing Remarks
Lawrence D. Burns, Professor of Engineering Practice,
University of Michigan

5:30 p.m. *Reception*

June 12, 2012

Agenda

8:00 a.m. ***Opening Remarks***
Lawrence D. Burns, Professor of Engineering Practice,
University of Michigan;
Chair, NAE Committee on Manufacturing, Design,
and Innovation

8:45 a.m. PARALLEL BREAKOUT GROUPS
High-value integrated innovation/design/manufacturing (I/D/M) is the only path forward for the nation. Is this statement true? Why or why not? What is preventing high-value integrated I/D/M? What can industry, academia, and government do on their own to enable it?

11:15 p.m. *Break*

11:30 a.m. **CLOSING PANEL**
Breakout Group Summary Remarks

Closing Remarks
Charles M. Vest, President, National Academy of
Engineering

12:30 p.m. ***Adjourn***

Appendix B

Biographical Information

ERIK BRYNJOLFSSON (*panelist*) is the director of the MIT Center for Digital Business at the MIT Sloan School of Management, a professor at the Sloan School, and a research associate at the National Bureau of Economic Research. His research examines the effects of information technologies on business strategy, productivity, and employment. His recent work studies data-driven decision making, the pricing implication of Internet commerce, and the role of intangible assets.

Brynjolfsson lectures worldwide on technology and strategy. *Businessweek* has profiled him as an "ebusiness visionary," and he is a director or advisor for several technology-intensive firms. His recent books include *Wired for Innovation: How IT Is Reshaping the Economy* and *Race Against the Machine: How the Digital Revolution Is Accelerating Innovation, Driving Productivity and Irreversibly Transforming Employment and the Economy*. His papers are available online (*http://digital.mit.edu/erik*); he also blogs at *www.economicsofinformation.com*, and can be followed on Twitter (@*erikbryn*). He has bachelor's and master's degrees from Harvard and a Ph.D. from MIT.

LAWRENCE D. BURNS (*planning committee member and speaker*) is professor of engineering practice at the University of Michigan (U-M). In addition to his U-M role, he is director of the Roundtable on Sustainable Mobility with the Earth Institute at Columbia University. His focus at both institutions is energy policy and transportation. Prior to joining the U-M faculty, Larry completed a 40-year career with General Motors (GM) on October 1, 2009. He left GM as vice president of research and development and strategic planning, a role in which he oversaw GM's advanced technology, innovation programs, and corporate strategy.

Burns holds a Ph.D. in civil engineering from the University of California at Berkeley, where he is a member of the Advisory Council for its Institute of Transportation Studies. He earned his bachelor's degree in mechanical engineering from General Motors Institute (now Kettering University) and his master's degree in engineering/public policy from U-M. He serves on the board of U-M's Automotive Research Center and the External Advisory Board for its Michigan Memorial Phoenix Energy Institute. In addition, he is a member of the Board of Trustees of the Midwest Research Institute and the Rochester Institute of Technology.

Dr. Burns was elected to the National Academy of Engineering in 2011. He has also been honored with Kettering University's Engineering Alumni Achievement Award for his contributions to the engineering profession (2000), the National Campaign for Hearing Health Leadership Award from the Deafness Research Foundation (2002), the Alumni Merit Award from the University of Michigan Industrial and Operations Engineering Department (2005), the ASM International Medal for the Advancement of Research (2007), the Society of Plastics Engineers Global Engineering Leadership Award (2007), the Golden Gear Award from the Washington Automotive Press Association (2008), the Industry Pioneer Award from the Alternative Fuel Vehicle Institute (2008), and the Fuel Cell Seminar & Exposition Award for demonstrating significant leadership in promoting the overall advancement of fuel cell technology (2009).

CURTIS R. CARLSON (*planning committee member, keynote speaker, and group discussion leader*), SRI president and CEO since 1998, is a world authority on creating value for customers through innovation. In 1973, he joined RCA Laboratories, which became part of SRI in 1987 as Sarnoff Corporation. There, Carlson started and helped lead development of HDTV technology that became the US standard.

His book with William Wilmot, *Innovation: The Five Disciplines for Creating What Customers Want*, describes how SRI's unique process for innovation can be applied to all types of government and commercial enterprises. He is a founding member of the Innovation Leadership Council for the World Economic Forum and was selected to serve on President Obama's task force for research and development.

Carlson received his B.S. in physics from Worcester Polytechnic Institute and his M.S. and Ph.D. degrees in atmospheric sciences from Rutgers University. His honors include a lifetime achievement award from Rutgers University's School of Engineering and the Otto Schade Prize from the Society for Information Display.

GARY L. COWGER (*panelist*) is chairman and CEO of GLC Ventures LLC, a management consultancy on business, manufacturing, and technology strategy. He is also chairman of the board of trustees at Kettering University and serves on the board of directors of Delphi Corporation. Cowger received his bachelor's degree in industrial engineering at General Motors Institute (now Kettering University) in 1970; his master's degree in management at the Massachusetts Institute of Technology in 1978; and he holds an honorary doctorate of humane letters from Lindenwood College (2002) and an honorary doctor of engineering from Kettering University (2007).

Mr. Cowger's career at General Motors spanned 45 years. He served in various capacities at GM and, at his retirement, was group vice president of GM Global Manufacturing and Labor Relations. In this position he was responsible for directing all of GM's manufacturing, manu-facturing engineering, and labor relations activities worldwide, and was a member of the Automotive Strategy Board and the Automotive Product Board. Cowger was instrumental in leading the development of several manufacturing technologies, including the use of math-based tools along with the adoption of synchronous and lean manufacturing at GM.

Mr. Cowger was elected to the National Academy of Engineering for his contributions to the GM Global Manufacturing System, which dramatically improved flexibility, quality, and productivity in automotive manufacturing. He received the M. Eugene Merchant Manufacturing Medal from the American Society of Mechanical Engineers and the Society of Manufacturing Engineers in 2010. Dr. Cowger was named a fellow of Stanford University in 2006, only the fifth recipient of this honor in 20 years. He was selected Automotive Industries' Executive of the Year (2004). He is the recipient of the Society of Automotive Engineers' Manufacturing Leadership Award (2003) and the Shien-Ming Wu Foundation's Wu Manufacturing Leadership Award (2001).

JONATHAN S. DORDICK (*panelist*) is the Howard P. Isermann Professor of Chemical and Biological Engineering at Rensselaer Polytechnic Institute. Prof. Dordick received his B.A. degree in biochemistry and chemistry from Brandeis University and his Ph.D. in biochemical engineering from the Massachusetts Institute of Technology. He has held chemical engineering faculty appointments at the University of

Iowa (1987–1998), where he also served as the associate director of the Center for Biocatalysis and Bioprocessing, and Rensselaer Polytechnic Institute (1998–present) where he also holds joint appointments in the departments of Biomedical Engineering, Materials Science and Engineering, and Biology. Prof. Dordick's research group includes chemical engineers, bioengineers, materials scientists, biologists, chemists, and microbiologists all focused on gaining a quantitative understanding of biological principles and applying them to advance bioengineering, nanobiotechnology, drug discovery, and biomanufacturing. Specific areas of current research include enzyme structure and function at biological-material interfaces, high-throughput drug and functional materials discovery, and biologically inspired nanocomposites for 2D and 3D functional architectures.

Prof. Dordick has received numerous awards, including the 2007 Marvin J. Johnson Award and the 2007 Elmer Gaden Award, both of the American Chemical Society, the 2003 International Enzyme Engineering Award, the 1998 Iowa Section Award of the American Chemical Society, and an NSF Presidential Young Investigator Award in 1989. He was elected a fellow of the American Chemical Society in 2010, a fellow of the American Association for the Advancement of Science in 2004, and a fellow of the American Institute of Medical and Biological Engineers in 1996. He serves on the scientific advisory boards for several biotechnology companies and venture capital firms and has cofounded a number of companies, including EnzyMed (now part of Albany Molecular Research, Inc.), Solidus Biosciences, and the Paper Battery Company. Dr. Dordick has published more than 300 papers and is an inventor/co-inventor on nearly 40 patents and patent applications.

KAIGHAM (KEN) J. GABRIEL (*panelist*) is acting director of the Defense Advanced Research Projects Agency (DARPA). He was sworn in as the deputy director of DARPA in July of 2009. Founded in 1958 as a response to the Soviet Union's launch of Sputnik, DARPA's mission is to prevent and create strategic surprise. Since its founding more than 50 years ago, this mission implies one imperative for the Agency: radical innovation for national security. Today, DARPA is the principal agency in the Department of Defense for research, development, and demonstration of high-risk, high-payoff projects for the current and future combat force.

Dr. Gabriel previously served at DARPA between 1992 and 1997. In 1992, he was recruited to start the Agency's Microelectromechanical

Systems (MEMS) program and grew the effort to more than $80 million annually with more than 70 projects. He was promoted to director of the Electronics Technology Office (1996–1997), where he was responsible for nearly $450 million annually in electronics technology programs including advanced lithography, electronics packaging, MEMS, optoelectronics, millimeter and microwave integrated circuits, and high-definition displays. Prior to DARPA, Dr. Gabriel was the founder, chairman and chief technical officer of Akustica, a semiconductor company commercializing MEMS sensors for consumer electronics products. Based in the United States with a global supply chain and customer base, Akustica pioneered the use of digital silicon microphones and shipped more than 5 million units to the PC/notebook industry before being acquired in 2009.

Widely regarded as the architect of the MEMS industry, Dr. Gabriel was named a Technology Pioneer by the World Economic Forum at Davos in 2003, one of 40 selected worldwide. He is the co-founding executive director of the MEMS Industry Group, the principal trade organization representing the MEMS industry globally. An international lecturer on innovation and technology development, Dr. Gabriel holds an S.M. and a Ph.D. in electrical engineering and computer science from the Massachusetts Institute of Technology.

ANITA GOEL, MD, Ph.D., (*planning committee member*) is chairman and scientific director of NANOBIOSYM and chairman and CEO of NANOBIOSYM DIAGNOSTICS. She is a globally recognized leader in the emerging field of nanobiophysics—a new science at the convergence of physics, nanotechnology, and biomedicine. Nanobiophysics integrates these three fields to reveal new scientific solutions to the world's most pressing challenges.

Dr. Goel has given expert testimony before the US Senate Subcommittee on Science, Technology and Innovation, advised President Obama's Strategy for American Innovation for the President's Council of Advisors on Science and Technology (PCAST), and helped build the roadmap for harnessing nanotechnology to stimulate the US economy. She has been a featured keynote speaker at many major international conferences, symposia, and university colloquia. Her pioneering contributions to nanotechnology and nanobiophysics have been recognized globally by prestigious honors and awards, including multiple awards from US government agencies. She received the Global Indus Technovator Award from MIT and was named one of the world's "Top 35 Science and Technology Innovators under the age of 35" by *MIT Technology Review* in 2005.

Dr. Goel is a member of the Board of Overseers of the Boston Museum of Science, a charter member of TiE (The Indus Entrepreneurs, a global organization of successful entrepreneurs engaged in the cycle of wealth creation and giving back to society), a fellow of the World Technology Network, a fellow-at-large of the Santa Fe Institute, an associate of the Harvard Physics Department, and an adjunct professor of the BEYOND Institute for Fundamental Concepts in Science at Arizona State University. She also serves on the National Board of the Museum of Science and Industry, the International Advisory Board of the Victoria Institute of Science and Technology, the Nanotechnology Advisory Board of the Lockheed Martin Corporation, and is a founding member of the Global Council for the Center for Healthcare Innovation (CHI).

Dr. Goel holds a Ph.D. in physics from Harvard University, an M.D. from the Harvard-MIT Joint Division of Health Sciences & Technology (HST), and a B.S. in physics with honors and distinction from Stanford University.

JAY GOLDEN (*keynote speaker*) is director of the Duke Center for Sustainability & Commerce, where he leads efforts to deliver impactful research and education programs on the important nexus of sustainability and manufacturing. He is also an associate professor of sustainable systems analysis in the Nicholas School of the Environment and the Pratt School of Engineering at Duke University.

He received his Ph.D. in engineering from the University of Cambridge and Master's Degree in environmental engineering and sustainable development from a joint program of the Massachusetts Institute of Technology and the University of Cambridge. He also holds a Professional Mastery of Project Management from Stanford University and has a bachelor's degree in management.

Dr. Golden co-founded and co-directed the Walmart-led Sustainability Consortium and founded the National Center of Excellence on SMART Innovations, which focused on engineering innovations for sustainable materials and renewable technologies. He was appointed to the UN Life Cycle Management Task Force and was named an AT&T Industrial Ecology Fellow. In 2009 he was awarded the Faculty Pioneer Award by the Aspen Institute for his leadership in the field of Sustainability Education and Research and was named by Ethisphere as one of the world's most 100 influential people in business ethics.

STEVEN MCKNIGHT (*group discussion co-leader*) is director of the Civil, Mechanical, and Manufacturing Innovation Division (CMMI) of the NSF Directorate for Engineering. Before that he was chief of the Army Research Laboratory (ARL) Materials Division, where he helped establish the Army's nanotechnology research program and twice co-chaired the Army's Nanotechnology Integrated Product Team. He also served as the Army's primary representative on agency, interagency, and international materials research coordination and advisory groups. His personal research focuses on advanced polymer composite materials and polymer adhesion science, including innovative composites manufacturing techniques using nontraditional consolidation and curing methods for structural composite materials and composite material repair, tailored nanoscale engineering of composite fiber reinforcement for ballistic applications, and fundamental studies on the degradation mechanisms of multicomponent, high-performance military coating systems. After receiving a B.S. in materials engineering from Virginia Tech, Dr. McKnight earned his Ph.D. in materials science and engineering from the University of Delaware. He has received two Army R&D Achievement Awards as well as the 1998 Paul A. Siple Memorial Award in recognition of outstanding research. He has published 33 journal articles and 19 government technical reports; he holds three patents, two patent applications, and two invention disclosures.

MICHAEL F. MOLNAR (*planning committee member and group discussion leader*) is the first chief manufacturing officer for the Commerce Department's National Institute of Standards and Technology (NIST). In his position he is responsible for planning and coordinating the Institute's broad array of manufacturing research and services programs and for serving as NIST's central point of contact with the White House and other agencies on policy issues and initiatives related to manufacturing. Mr. Molnar has extensive industrial experience and leadership roles including advanced manufacturing, metrology, manufacturing systems, quality, technology development, sustainability, and industrial energy efficiency.

Before joining NIST, Mr. Molnar was director of environmental policy and sustainable development at the Columbus, Indiana, headquarters of Cummins Inc., a $14 billion international company that designs and manufactures commercial engines and power generation systems. Other credentials include his service as a federal fellow in the White House Office of Science and Technology Policy and election as fellow of both the American Society of Mechanical Engineers and the Society of Manufacturing Engineers. He is a licensed professional engineer, a certified manufacturing engineer. and a certified energy manager. He received an M.B.A. from the University of Notre Dame and both an M.S. in manufacturing systems engineering and a B.S. in mechanical engineering from the University of Wisconsin. He is an active member of professional societies, consortia, and volunteer organizations.

PANOS Y. PAPALAMBROS (*planning committee member and group discussion co-leader*) is the Donald C. Graham Professor of Engineering and a professor of mechanical engineering at the University of Michigan. He is also professor of architecture and of art and design. In addition, he is executive director of Michigan Interdisciplinary and Professional Engineering.

Born in Patras, Greece, Dr. Papalambros attended the National Technical University of Athens (Ethnikon Metsovion Polytechnion) and earned a diploma in mechanical and electrical engineering in 1974. After moving to California, he attended Stanford University and earned his M.S. degree in mechanical engineering in 1976 and his Ph.D. degree (Design Division, Mechanical Engineering) in 1979. At Michigan he has served as a faculty member since 1979.

His research interests include design science and optimization, with applications to product design and development, automotive systems, such as hybrid and electric vehicles, architectural design, and design of large complex engineered systems. With D.J. Wilde, he co-authored the textbook *Principles of Optimal Design: Modeling and Computation* (1988, 2000), and he has published more than 300 articles in journals, conference proceedings, and books. He is a member of the American Society of Mechanical Engineers (ASME), INFORMS, MPS, Society of Mechanical Engineers (SME), Society of Automotive Engineers (SAE), International Society of Structural and Multidisciplinary Optimization (ISSMO), American Institute of Aeronautics and Astronautics (AIAA), American Association of University Professors (AAUP), American Society for Engineering Education (ASEE), and the Design Society. He is also a fellow of ASME and SAE. Dr. Papalambros serves on the editorial boards of the journals *Artificial Intelligence in Engineering Design and Manufacturing, Engineering Design, Engineering Optimiza-*

tion, Computer-Integrated Engineering, Structural and Multidisciplinary Optimization, and the Journal of Engineering Simulation and he is chief editor of the *ASME Journal of Mechanical Design*.

Dr. Papalambros is the recipient of the ASME Design Automation Award (1998), ASME Machine Design Award (1999), JSME Design and Systems Achievement Award (2004), and the ASME Joel and Ruth Spira Outstanding Design Educator Award (2007). In 2009 he received the Stephen S. Attwood Award, the highest honor of the College of Engineering at the University of Michigan.

G.P. "BUD" PETERSON (*panelist*) is the 11th president of Georgia Tech. His research interests have focused on the fundamental aspects of phase change heat transfer, including heat transfer in reduced-gravity environments, boiling from enhanced surfaces, and some of the earliest work in the area of flow and phase change heat transfer in microchannels. Early investigations focused on applications involving the thermal control of manned and unmanned spacecraft and progressed through applications of phase change heat transfer, to the thermal control of electronic components and devices. More recently, investigations have included fundamental applications of phase change heat transfer to the field of biotechnology, including the in situ treatment of cancerous tissue using hypo- and hyperthermia to arrest epileptic seizures through the rapid cooling of localized brain tissue, which required highly efficient heat dissipation devices capable of dissipating thermal energy to surrounding tissue.

Dr. Peterson has played an active role in helping to establish the national education and research agendas, serving on numerous industry, government, and academic task forces and committees. He has served on a number of congressional task forces, research councils, and advisory boards. In addition, he has served as a member of the board of directors and vice president for education for the American Institute of Aeronautics and Astronautics (AIAA) and co-chair of the Government Relations Committee of the Association of Public and Land-grant Universities (APLU). He is a member of the National Science Board (NSB), the US Council on Competitiveness, the National Advisory Council on Innovation and Entrepreneurship (NACIE), and he was recently appointed by President Barack Obama as a member of the Advanced Manufacturing Partnership (AMP) Steering Committee. Dr. Peterson is a fellow of both AIAA and the American Society of Mechanical Engineers. He is the author or coauthor of 14 books or book chapters, 195 refereed journal articles and more than 150 conference publications, and holds eight patents with three others pending. He is a member of several professional organizations and the recipient of numerous national and international honors and awards for both teaching and research.

LOUIS W. RASSEY (*panel moderator*) is a principal in the Chicago Office of McKinsey & Company. Since joining in 2003, Rassey has been a leader in the firm's Manufacturing, Operations and Private Equity Practices, with particular expertise in integrated operations improvement and operations strategy. In partnership with the McKinsey Global Institute (MGI), he is coleading the firm's effort to understand the "Future of Manufacturing" and its implications for how countries and companies compete.

Rassey serves clients in the medical device, pharmaceutical, consumer products, automotive, and industrial sectors. His experiences include leading global efforts and performance transformations across operations disciplines—including innovation strategy, product design, manufacturing, supply chain, procurement, business development, and corporate strategy.

Before joining McKinsey, Rassey worked for automotive and high-tech firms. He holds an M.B.A. and an M.S. degree in mechanical engineering from the Massachusetts Institute of Technology where he was a Leaders for Manufacturing Fellow. He also holds an M.S. degree in engineering management from the University of Michigan-Dearborn, and a B.S. degree in mechanical engineering from the University of Notre Dame.

JONATHAN J. RUBINSTEIN (*planning committee member and panelist*) is former executive chairman and CEO, Palm Inc. Rubinstein has helped launch some of the most influential computing products of our time. He was Palm's chairman and CEO before its acquisition by HP and was the driving force behind the company's return to innovation with its award-winning webOS software and innovative smartphone devices. As head of the Palm global business unit, he was leading HP's efforts in the mobility space, responsible for webOS software development and webOS-based hardware products.

As a member of Apple's senior executive staff, he was instrumental in conceiving the iPod and, as head of hardware engineering, led the rapid rollout of the iMac, a product that revitalized Apple and revolutionized personal computer design. Before joining Apple, he built his career at computer companies including Hewlett-Packard, Stardent, and NeXT, and founded his own company, Firepower Systems Inc.

Rubinstein is a member of the National Academy of Engineering and a senior member of the IEEE. He received bachelor's and master's degrees in electrical engineering from Cornell University and a master's degree in computer science from Colorado State University.

MATT SAKEY (*group discussion leader*), an expert in cognitive development and interactivity, is a professional analyst and consultant for the $50 billion international video games industry. His work ranges from supporting game developers and publishers to designing game studies curricula at the university level. A featured monthly columnist for the International Game Developers Association (IGDA) and contributor to a series of university textbooks on game design and ludology, he owns the popular media criticism outlet *www.tap-repeatedly.com* and is a highly sought lecturer on interactive entertainment and training.

In addition to his work in the games industry, Mr. Sakey develops training materials for corporate clients seeking to maximize knowledge transfer and retention through the use of interactive simulations and multimedia tools.

WILLY SHIH (*panel moderator*) is a Professor of Management Practice at the Harvard Business School. His interests are in national competitiveness and capability development by firms in emerging markets, global sequential production systems, and the management of science and technology intensive businesses. Before joining the Harvard Business School, he spent 18 years in the computer industry and 10 years in consumer electronics.

Dr. Shih has two S.B. degrees from MIT and a Ph.D. from the University of California at Berkeley. He is on the board of directors of Flextronics International, and he chairs the Technical Advisory Board for QD Vision, Inc., Watertown, Massachusetts.

STEPHANIE SHIPP (*group discussion leader*) specializes in the assessment of science and technology projects, programs, and portfolios. Her work spans topics related to innovation and competitiveness with recent emphasis on advanced manufacturing, the role of federal laboratories, and funding of high-risk/high-reward research. Before joining the Science and Technology Policy Institute, she was the director of the Economic Assessment Office in the Advanced Technology Program at the

National Institute of Standards and Technology. Prior to that, she led economic and statistical programs at the Census Bureau, the Bureau of Labor Statistics, and the Federal Reserve Board. She is a fellow of the American Statistical Association and has held several leadership positions in the ASA. She was a member of the international advisory board for VINNOVA, Sweden's innovation agency. Recently, she led an expert panel to evaluate the Swedish Research Council's Linnaeus Grants. She holds a B.A. from Trinity College, Washington, DC, and a Ph.D. in economics from George Washington University.

LAURA J. STEINBERG (*panel moderator*) is dean of Syracuse University's L.C. Smith College of Engineering and Computer Science and professor in the Civil and Environmental Engineering Department. She also holds an appointment as professor in the Department of Public Administration and International Affairs in Syracuse University's Maxwell School of Citizenship and Public Affairs.

Dean Steinberg earned a B.S. in civil and urban engineering from the University of Pennsylvania and master's and doctoral degrees in environmental engineering from Duke University. Prior to joining academia, Dean Steinberg worked for five years in the consulting engineering field.

Among Dr. Steinberg's initiatives as dean are diversification of the faculty body, completion of a grass-roots strategic planning effort, incorporation of creative expression in the engineering curriculum, and significant growth in the college's research and graduate programs in cybersecurity, energy engineering, and biomaterials.

CHAD SYVERSON (*planning committee member and group discussion leader*) is a professor of economics in the Booth School at the University of Chicago. His research spans several topics, with a particular focus on the interactions of firm structure, market structure, and productivity. His work has been published in top journals and has earned several National Science Foundation Awards, Olin Foundation Grants, and a Brookings Dissertation Fellowship.

Dr. Syverson is an associate editor of the *Rand Journal of Economics*, an editorial board member of the *B.E. Journal of Economic Analysis & Policy*, and a research associate of the National Bureau of Economic Research in its Productivity, Industrial Organization, Environmental and Energy Economics, and EFG Programs. He also serves on the board of the Chicago Census Research Data Center. Prior to these appointments, Dr. Syverson was a visiting scholar at the Federal Reserve Bank of Minneapolis and a mechanical engineer co-op for Loral Defense Systems and Unisys Corporation.

He earned two bachelor's degrees in 1996 from the University of North Dakota, one in economics and one in mechanical engineering. He earned a master's degree in 1998 and a Ph.D. in 2001, both in economics from the University of Maryland. Dr. Syverson joined the Chicago Booth faculty in 2008.

REBECCA R. TAYLOR (*planning committee member*) is senior vice president for the National Center for Manufacturing Sciences (NCMS), the largest not-for-profit research and development consortium in North America focused on manufacturing. NCMS consists of more than 300 member corporations working toward the goal of improving US manufacturing competitiveness. Ms. Taylor is responsible for the operation of the organization's government efforts, liaison with members of Congress and the administration, oversight of NCMS government programs, and overall management of the Washington, DC, and Bremerton, Washington, offices.

Until August 1991, Ms. Taylor was as an international trade analyst for the US Department of Commerce. In this position she served as a principal in machine tool trade negotiations with the governments of Japan and Taiwan, representing the Bureau of Export Administration. She was also the Bureau's representative to the interagency working group on the Intelligent Manufacturing Systems program for multilateral R&D cooperation. Prior to her tenure at the Department of Commerce, Ms. Taylor worked for the US Department of State in the Bureau of Intelligence and Research. Her portfolio included issues such as international border disputes, refugee and immigration issues, and international terrorism.

In addition to her position at the NCMS, Ms. Taylor is the vice chairman of the Board of Directors for the Robotics Technology Consortium and a board member of the Joint Defense Manufacturing Task Force of the National Coalition for Advanced Technologies. She is also on the Executive Committee of the National Defense Industrial Association's Manufacturing Division and member of Women in Government Relations and Women in Defense and the International Women's Forum. Trained in Economics and Political Sciences, Ms. Taylor holds a bachelor's degree from the George Washington University and a master's degree from the London School of Economics and Political Science.

CHARLES M. VEST (*speaker*) is president of the National Academy of Engineering. He served as MIT's president from 1990 through 2004. He earned a B.S. degree in mechanical engineering from West Virginia University in 1963 and received his M.S. and Ph.D. degrees in 1964 and 1967, respectively, from the University of Michigan, where he later held the positions of dean of engineering, provost, and vice president for academic affairs. He is the recipient of 17 honorary doctoral degrees, the 2006 National Medal of Technology, and, in 2011, the Vannevar Bush Award from the National Science Board. Dr. Vest served on the President's Committee of Advisors on Science and Technology (PCAST) during the Clinton and Bush administrations. Selected as a member of the bipartisan Commission on the Intelligence Capabilities of the United States Regarding Weapons of Mass Destruction, which completed its report in 2005, Dr. Vest brought a strong science and engineering background to the analysis. He led a US Department of Energy task force on the future of science programs in 2002–2003 and chaired a presidential advisory committee on the redesign of the International Space Station in 1992–1994. Dr. Vest was vice chair of the Council on Competitiveness for eight years, is a former chair of the Association of American Universities, and served on the US Secretary of Education's Commission on the Future of Higher Education and the Secretary of State's Advisory Committee on Transformational Diplomacy.

DAWN WHITE (*panelist*) has expertise in manufacturing R&D and technology company formation and financing, with extensive research experience in a range of materials processing fields, including welding and joining science, and rapid prototyping and tooling. She is founder and president/CTO of Accio Energy, and recently joined the Board of Directors of the National Center for Manufacturing Sciences. She has a B.S. and M.S. in metallurgical engineering and a Ph.D. in mechanical engineering from the University of Illinois. She has published more than 30 technical papers and is a productive inventor, having been awarded 20 US patents with several additional patents pending.

Previously Dr. White founded and was CEO of Ann Arbor–based Solidica Inc., based on the Ultrasonic Consolidation rapid prototyping process, which she invented and commercialized as the Formation™ rapid prototyping machine. Before starting Solidica, she worked in developing and deploying advanced manufacturing technology at Ford Motor Company, MTS Systems, and the US Army Construction Engineering Research Laboratory.