The term “innovation” denotes a process whereby a promising idea or an emerging technology is transformed into a practical solution — a marketable product, process or business model — at a scale sufficient to meet some societal need. Technological innovation is distinctly different from both scientific discovery and engineering invention. A critical step that follows a discovery or an invention, the translational step, is the key that enables product realization and wealth creation. A successful innovation process reduces technical and market risks and enables scale-up to manufacturing.

Teasing out the components of this process, the U.S. National Academies provided a much broader definition in a recent report: “Innovation commonly consists of being first to acquire new knowledge through leading-edge research; being first to apply that knowledge to create sought-after products and services, often through world-class engineering; and being first to introduce those products and services into the marketplace through extraordinary entrepreneurship.”

The United States still leads the world in two of these three stages of innovation, often being “first to acquire” and “first to introduce,” but it has been steadily lagging in applying the knowledge that its creative minds generate. Being “best in the world” in scientific discoveries is important,
but it is not sufficient in itself to keep any nation viable in today’s global economy. Investments in science produce indispensable knowledge, but it is by applying that knowledge through rigorous engineering and development that people and nations produce wealth, thereby achieving economic strength and national security.

Consider who ultimately capitalized on the basic research investments made by a variety of U.S. federal agencies (Figure 1) that led to the development of MP3 technologies. The MP3 device “itself is innovative, but it built upon a broad platform of component technologies, each derived from fundamental studies in physical science, mathematics and engineering,” according to the White House Domestic Policy Council. While this statement is correct, the reality is that the subsequent development and manufacturing of component technologies, and thus the creation not only of wealth and jobs but also of the foundation for the next generation of innovations, took place abroad. The development and commercialization of the device’s signal-compression technology were picked up by Germany’s Fraunhofer Institute for Applied Research. The supply chains that support the manufacture of the hard drive, lithium-ion battery, LCD display and DRAM cache are all based in Asia. The jobs designing and making these hugely popular and technically complex products are there, too.

That the United States has fallen behind in the application function can be seen in its trade deficits in the high-tech sector. Its trade balance in advanced technology products (ATP), which have long been a bastion of American ingenuity, fell into the red for the first time in 2002 (Figure 2), when it came in at a negative $16.5 billion, and worsened over 10 years of deficits to reach negative $91.5 billion for 2012.
This is not due to a lack of national investment: In total dollars, the federal research and development (R&D) budget for Science and Technology was nearly $140 billion in 2011, and the country has invested well over $2 trillion in the past 20 years. Private-sector R&D investments, mostly in product development through incremental innovation, were upwards of $250 billion. The United States’ total R&D investment of nearly $400 billion was twice that of its nearest competitor. Yet by 2011, the U.S.’s ATP-goods deficit exceeded the total net foreign earnings from the intellectual-property royalties and fees, including franchise fees, booked by all “U.S.-incorporated” companies, from Apple and Intel to Starbucks and McDonald’s. The claim that the country can prosper by simply creating technologies here and then letting them be manufactured “over there” is misguided. That path is neither economically sustainable nor governmentally justifiable, and it erodes confidence in America’s future.

At this point, the United States has lost ground or is on the verge of losing ground to global competitors in many economically important advanced-technology industries that got their start in America. Among them are flat-panel displays, lithium-ion batteries, solar cells and nanotechnology. Unless cultural and political awareness of engineering’s importance to the U.S. economy increases, several strengths upon which its comparative advantage has traditionally been based — its ability to produce high-technology goods, its highly skilled workforce and its high productivity — will continue to diminish.
FIGURE 1: Research Funded by DOD, NSF, NIH, DOE and NIST that Contributed to the Breakthrough Technologies Embedded in MP3 Devices

IMPACT OF BASIC RESEARCH ON INNOVATION

- Micro Hard Drive Storage
- Li-ion Battery
- LCD Display
- DRAM Cache
- Signal Compression

1988: "Giant magnetoresistive effect" (GMR) is discovered, creating the field of spintronics

1988: Thin film transistor LCD displays emerge

1990: Development of the lithium-ion battery

1965: The “Fast Fourier transform” revolutionizes the field of signal processing

1960-70s: Very large Scale Integration (VLSI) system and circuit design pioneered
THE MISSING MIDDLE:
THE APPLICATION OF RESEARCH RESULTS

The implications of this weakening go well beyond the accounts-receivable column. Companies choose to expand or set up new manufacturing facilities based on many factors, among which are taxes and trade regulations, as well as access to capital, markets and a skilled workforce. But two additional factors that are often overlooked matter even more: engineering know-how and the presence of supply chains. Many electronics products, the Amazon Kindle and Apple iPhone being good examples, can no longer be made in the United States, primarily because their supply chains are now rooted in Asia. A similar erosion of U.S. supply chains in defense-critical technologies or products would be strategically dangerous.

The fact is that, in high-technology industries, manufacturing and R&D are closely knit. Ample evidence shows that combining the two is key to fueling real innovation, and that the co-location of R&D and manufacturing facilities adds value to each. Promising ideas must be matured through translational R&D if they are to end up in products that meet performance goals and are at the same time cost-effective, reliable and safe. Only a small
fraction of discoveries and first-generation inventions prove worthy of scaling up, and it is during scale-up and initial manufacturing that many improvements in design and efficiency are made that can then feed back to follow-on cycles of innovation. It is for this reason that the failure to manufacture each generation of advanced-technology products places at risk the ability to innovate the next generation of products (Figure 3). This has been well understood in industry for almost a decade but has been little recognized by the political establishment.

Declining expertise leads to the abandonment of facilities and infrastructure, which in turn has a negative impact not only on the skilled workforce and supply chains but on the whole culture of innovation. The offshoring of cutting-edge manufacturing is inevitably followed by the offshoring of R&D, something that over the past two decades has brought with it a significant change in the scope of corporate R&D in the United States.
Increasingly, in the interest of staying competitive in the moment, private-sector R&d has become focused on the immediate goal of turning out current products more quickly and more cheaply. The majority of America’s industrial R&D is now essentially just β — and short-term, product-development β at that.

All the while, the bulk of federal R&D investment has remained focused exclusively on the R, the basic research that has no direct or clear relation to the industrial D except in a few sectors like pharmaceuticals and electronics, and even in these two sectors the United States runs large trade deficits. The result has been a gap — “the missing middle” of translational R&D — between the United States’ cutting-edge science and its ability to create new companies and sell new products. Put another way, America excels in science, finance and marketing but is falling behind in the kind of engineering that drives innovative growth.

**TRANSLATIONAL RESEARCH**

The United States is by far the world’s largest R&D performer: Its total of $400 billion in 2009 accounted for nearly 31 percent of global R&D spending. R&D performed by businesses in the United States came to an estimated $275 billion, about 71 percent of all U.S. R&D that year, while federal R&D accounted for approximately $125 billion.

While at first glance the portfolio represented in Figure 4 may appear fairly balanced, in reality it reveals a gaping hole in the American innovation pipeline: Translational R&D, which is necessary to mature nascent technologies and to assure their manufacturing readiness, goes largely unfunded. The federal government’s R&D investments are primarily in basic research, and industry’s are primarily in applied R&D, or perhaps no more than β, being focused as they are on incremental innovations aimed at making existing products better. There is very little connecting federal research and industrial development in most technology sectors.

Basic scientific research has traditionally been considered a “public good” and its funding, therefore, the responsibility of government. But while science is the ultimate source of most technological innovation, it does not by itself turn out the products and services that generate wealth. Creation of the Internet, for example, involved little or no new basic
science, but it did require significant investments in precompetitive applied research, or translational research, directed at such enabling technologies as communication protocols and networking infrastructure. These were investments that the private sector did not make because their time horizons were too long and their payoffs too difficult for any one company to capture. Now that the Bell Labs of yesteryear have disappeared and the
scope of corporate R&D has narrowed significantly, the U.S. government has a major role to play in supporting translational research, which alone can ensure that the fruits of federally funded basic research are transitioned to homegrown products.

It is impossible to know in advance which specific investments in basic research will lead to useful discoveries. It is equally difficult to predict which useful discoveries will result in scalable, safe, reliable and cost-effective technologies without the intermediate step that translational research represents. For this reason, the lack of investment in translational research by federal and private sources over the past 20 years has created a significant innovation gap in the United States, the results of which are expressed in lackluster economic growth.

**THE LABOR-COST MYTH**

Low-cost labor is not the reason that the United States is losing its market share in high-technology products, whose labor content tends, in any event, to be quite low. The case of Germany’s vibrant manufacturing sector puts this into perspective. Labor costs in Germany are almost 33 percent higher than those in the United States; in addition, although German companies pay marginal corporate tax rates that are slightly lower than those of their U.S. competitors, they pay nearly 25 percent more for energy (figure 5). Yet in 2011 the difference in the two nations’ trade balances in goods reached almost $1 trillion: The United States had a deficit in goods of $738 billion, Germany a surplus of over $200 billion. Another potentially crucial difference: Even though the U.S. federal government invests six times as much in R&D as Germany does, it invests less than one-third as much in industrial technologies. Seen in this light, the U.S. deficit in advanced-technology products suggests that the benefits of government R&D investments are trickling down to neither American industry nor American taxpayers in the form of high-wage manufacturing jobs.


**FIGURE 5: Various Inputs and Economic Output of German and U.S. Manufacturing Sectors**

<table>
<thead>
<tr>
<th></th>
<th>U.S.</th>
<th>Germany</th>
</tr>
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<tbody>
<tr>
<td>Trade Balance ($B) (2011)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GOODS</td>
<td>-738</td>
<td>+214</td>
</tr>
<tr>
<td>SERVICES</td>
<td>+178</td>
<td>-30</td>
</tr>
<tr>
<td>NET</td>
<td>-560</td>
<td>+184</td>
</tr>
<tr>
<td>Manufacturing as % GDP (2010)</td>
<td>13</td>
<td>21</td>
</tr>
<tr>
<td>Hourly Compensation of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturing Workers (2011)</td>
<td>$35.53</td>
<td>$47.38</td>
</tr>
<tr>
<td>Govt. Research Budget in</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Billions of Dollars (2011)</td>
<td>164</td>
<td>26</td>
</tr>
<tr>
<td>Investment in Industrial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production and Technology</td>
<td>0.963(0.6%)</td>
<td>3.3 (12.7%)</td>
</tr>
<tr>
<td>As Percent of Nondefense R&amp;D</td>
<td>1.2%</td>
<td>13.5%</td>
</tr>
<tr>
<td>Share (%) of Business R&amp;D</td>
<td>69.6</td>
<td>90.0</td>
</tr>
<tr>
<td>Expenditures on Manufacturing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R&amp;D as % GDP</td>
<td>2.68</td>
<td>2.53</td>
</tr>
<tr>
<td>Raw Cost Index of Manufacturers</td>
<td>$0.47</td>
<td>$0.52</td>
</tr>
<tr>
<td>Statutory Corporate Tax Rates</td>
<td>39.1</td>
<td>30.2</td>
</tr>
<tr>
<td>(2012)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social Insurance Expenditures</td>
<td>33</td>
<td>42</td>
</tr>
<tr>
<td>and Other Labor Taxes (% of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compensation)</td>
<td></td>
<td></td>
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<tr>
<td>Industrial Pollution Abatement</td>
<td>6.2</td>
<td>6.0</td>
</tr>
<tr>
<td>and Control Expenditures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(% of Value Added)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>End-User Industry Energy Costs</td>
<td>100.0</td>
<td>124.7</td>
</tr>
<tr>
<td>(Index U.S. = 100)</td>
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</tbody>
</table>
THE CHANGING FACE OF U.S. MANUFACTURING

Over the past two decades, while the U.S. manufacturing sector has been struggling through a period of major change and downsizing, other nations’ industrial production and exports have surged. In the 1990s, shedding low-cost, labor-intensive production was taken on as a major challenge in the United States, whose economic future was assumed to be in technology-intensive, high-productivity, high-skilled manufacturing. But manufacturing’s contribution to U.S. GDP has simply continued along the downward trajectory that has taken it from above 25 percent through the 1950s and 1960s to 17 percent in 1990 and down to its current 11.5 percent. The nation’s manufacturing employment has declined as well, from a peak of 19.5 million manufacturing payroll jobs in 1979 to fewer than 12 million in 2012.

The picture is notably different in two other developed countries, Germany and Japan. Although the levels of manufacturing employment in both have declined significantly and steadily since the 1970s, Germany’s seems to have leveled off at 20 percent of its workforce and Japan’s at 16.8 percent, and the manufacturing sectors of both have remained healthy throughout the recent worldwide economic downturn. These two countries can be expected to continue thriving in the advanced-manufacturing sector. At the same time, emerging economies that have fully embraced lower-tech manufacturing will be working harder to move up the value chain. To contend for leadership in advanced-technology products, the United States must invest in industrial infrastructure; in basic, translational and applied research; and in a highly trained workforce at all levels, from skilled production labor to high-quality graduate engineers.

Maintaining a strong research infrastructure is central to competing in high-technology products because there is ample evidence to suggest that real innovations come about when R&D and advanced manufacturing are co-located. But since U.S.-based manufacturing firms’ rate of investment in R&D in the period 1999-2007 was three times as high outside the United States as it was at home, it is evident that much of that co-location is sited overseas. Once U.S. corporations had begun offshoring lower-tech manufacturing — the production of toys and shoes, for example — higher-value-added activities like engineering design and development
also started moving abroad. R&D then followed. The same occurred in high-tech manufacturing, starting in 2001 with semiconductors and other electronic components and systems.

Thirty years ago, innovations would take root in the United States first. Years would pass before a product became a commodity item, at which point foreign companies might start by producing its components and then, a few years down the road, go on to make the entire product. In the cases of machine tools, robots, MRI machines, computers and LCDs, several years went by before U.S. manufacturers uprooted their domestic operations and reestablished them overseas. As years passed, however, the time it took to relocate manufacturing began to shrink: The migration time for LCD manufacturing was much shorter than that for MRI machines. It became the norm that the United States would play the role of technology inventor and that the manufacturing would subsequently move to other countries.

There is no shortage of examples, both past and present, indicating that whoever fails to manufacture a given generation of advanced-technology products loses the ability to innovate the next generation:

Lithium-ion batteries: The United States’ loss of leadership in the consumer-electronics device industry led to its loss of leadership in lithium-ion batteries. Sony bought lithium-ion battery technology from the United States in the early ’90s and has diligently improved it to meet the demands of the personal-computer industry. Having abandoned the lead it had in lithium-ion batteries 30 years ago, the United States must now work hard to regain a foothold in the multi-billion-dollar automotive lithium-ion battery industry.

Electronic displays: In the 1980s, U.S. companies started offshoring the assembly of printed-circuit boards to China, South Korea and Taiwan. As those countries gained technical know-how and moved up the value
chain to engineering design, development and systems integration, they began manufacturing entire personal computers. Today, virtually all Windows-based PCs and notebooks are designed and manufactured in Asia. With the Kindle, what had been invented in the United States was never manufactured at home. Massachusetts-based E-ink, developer of the electronic ink that changes the appearance of screens without illuminating them, had to go to Taiwan to find an LCD manufacturer for its invention, since none are left in the United States. This supplier, Primeview, then purchased E-ink and moved its operations to Taiwan to bring it closer to the rest of the supply chain needed to manufacture each new version of the Kindle. And because the infrastructure, manufacturing expertise and supply chains for LCD/LED technology are all located in Asia, next-generation flexible displays — expected to become another multi-billion-dollar industry — are unlikely to be manufactured in America either. The supply chain won’t be in the United States, and neither will any of the jobs.

**Solar cells:** Silicon Valley’s Applied Materials, the world’s leading manufacturer of equipment for making solar cells, recently constructed the world’s largest private solar R&D facility in China to leverage proximity to the world’s largest solar-manufacturing hubs. In view of such trends, the chances are good that soon the United States will no longer be manufacturing next-generation solar cells.

**Nanotechnology:** Lux Research in a 2010 report benchmarked various countries on their nanotechnology activity and technology-development strength. Germany, Japan, South Korea, Taiwan and the United States all ranked high in nanotechnology activity — but the United States ranked lowest of the five in technology-development strength and has been falling farther behind ever since. It is also important to note that U.S. technology-development strength moved in the wrong direction between 2007 and 2009 (Figure 6).
FIGURE 6: Ranking the Nations on Nanotech: Hidden Havens and False Threats

Source: Lux Research Report, August 2010

The diagram illustrates the technology development strength of various nations from 2007 to 2009. The nations are categorized into different quadrants based on their innovation and development in nanotechnology:

- **Ivory Tower** (high innovation, high development)
- **Dominant** (high innovation, moderate development)
- **Minor League** (moderate innovation, high development)
- **Niche** (moderate innovation, moderate development)

The nations are represented as dots, with their positions indicating their performance in technology development over the years.
As supply chains take root in faraway lands, it becomes more difficult not only to manufacture advanced-technology products at home, but also to innovate. Even when a marketable product has been successfully created in the United States, supply chains need to be nearby if manufacturing — the step where the most wealth creation occurs — is to take place domestically. And innovation will necessarily join manufacturing in moving to where supply chains exist. Examples like E-ink provide evidence that the “invent here, manufacture there” model is no longer economically sustainable — if it was, in fact, ever valid at all — and expose a big gap in America’s innovation pipeline. By any strict definition, the United States has not done significant technological innovation for a long time. It continues to excel in scientific discoveries and in some engineering inventions, but not in the transition of inventions into products that society wants. It is important for the country to recognize this fundamental change before it is too late.

THE LABOR-PRODUCTIVITY MYTH

The U.S. has lost nearly 6 million manufacturing jobs over the last decade, 3.4 million of them vanishing in the years 2000-07, before the Great Recession began. Many attribute the job losses to an increase in labor productivity, but this claim is erroneous. As Stephen Ezell and Robert Atkinson11 have demonstrated, 15 of the 19 manufacturing sectors that account for 79 percent of America’s manufacturing GDP experienced contractions in output between 2000 and 2009. That the decline was primarily an effect of offshoring, not of productivity gains, has been documented by other economic researchers, including Gregory Tassey12 of the National Institute of Standards and Technology (NIST); Susan Houseman13 of the Upjohn Institute; and, later, Susan Helper,14 who provides a clear explanation for the origin of the mistaken belief that productivity gains were behind the drastic job cuts of the past decade (figure 7).
Contributing to this misperception is the fact that U.S. government statistics on labor productivity, which are reported by the Bureau of Labor Statistics (BLS), overstate manufacturing productivity for three primary reasons:

I. Computer-industry statistics confound manufacturing productivity with product performance. According to BLS, annual productivity growth in the computer and electronics sector averaged about 27 percent. This change resulted far more from an improvement in the performance of computer chips, which continued to be produced on the same production lines by more or less the same number of employees, than from the same quantity of goods being produced by less labor. The notion that the latter was responsible is clearly misguided.
2. Imported inputs are not included when domestic labor productivity is computed. Value added is measured as “sales minus the cost of materials,” but there are no data comparing the costs of inputs imported from different places.

3. Although the goods produced by temporary workers are counted as manufacturing output, the temporary workers themselves are not counted as manufacturing workers in the official statistics.

When corrections are made for these three sources of flawed calculation, U.S. manufacturing’s annual productivity growth comes out at 2.3 percent in the period 1997-2007, not at 5.4 percent as reported by BLS. Even so, at 2.3 percent, productivity growth in manufacturing was higher than the 1.8 percent posted by the private sector as a whole.

**THE PROFILE OF AMERICAN ENGINEERING IS TOO LOW**

In light of the National Academies’ definition of innovation as in part the application of knowledge, “often through world-class engineering,” any attempt to revitalize America’s manufacturing — and its transition of promising ideas into marketable products or processes — must go hand in hand with revitalizing the U.S. system of engineering education and engineering research.

“Engineering is not science, and confusing the two keeps us from solving the problems of the world,” the engineering professor and author Henry Petroski has lamented on more than one occasion.¹⁵ Yet, many engineering researchers become uncomfortable whenever a clear distinction is drawn between engineering and science, and some of them would argue that, nowadays, “engineering science” is the best term to describe what they do. But science attempts to understand and explain the world through experimentation and analysis, while engineering is about synthesis: Scientific discoveries may provide the foundation for engineering’s creations, but these creations involve practical products and processes. Still, many in the engineering field, including agencies that fund its work, have come to regard publication in respected journals — especially scientific journals — as a worthy final outcome of engineering research.
In a departure from America’s history of significant engineering efforts and outcomes, the vast majority of current U.S. research programs explicitly emphasize the scientific aspects of a problem, showing a purely analytical bent. The most prestigious of the country’s granting agencies, the National Science Foundation (NSF), employs the same yardstick to measure the “intellectual merit” and “broader impacts of research” in engineering as it does to evaluate science. The seemingly innocuous generalization of science to include engineering has had real consequences in the past three decades: It has nourished science, discovery and publication at the expense of engineering, invention and innovation.

One of the outcomes is that the dissemination of knowledge is held in higher regard than the application of knowledge. Publication is the true currency of science disciplines, as evidenced by academia’s “publish or perish” model. In contrast, when engineering development, which takes place through the application of knowledge, is the goal, dissemination becomes less important. It can even be counterproductive before a product is at least partially developed and the intellectual property involved is protected. Engineering professionals must strive for innovation whose impact extends far beyond the academy to society at large. It is important, therefore, that influential institutions like NSF recognize that basic research in engineering does not have to be removed from reality, and that appropriate metrics for real engineering outcomes be established.

How a government allocates its resources is both a reflection of and an influence on the prevailing mindset. To illustrate, of the total U.S. federal research investment in science and engineering for 2008, approximately one-seventh (Figure 8) was allocated to engineering development and six-sevenths to various scientific fields. Although the acronym identifying its “STEM Education” effort stands for “Science, Technology, Engineering and Mathematics,” NSF spends only $15 million annually on engineering education, barely more than 1 percent of the $1.4 billion it directs to education in science and mathematics (Figure 9). Federal research
expenditures for 2011 were 8.1 percent above their 2001 level, with more of the gains going to life sciences than to other disciplines. Engineering, whose research expenditures went down 4.3 percent in 2011, was the only field that saw a decrease that year. The Defense Department (DOD) still accounts for nearly one-third of federal investment in engineering, but there has been a steep decline in DOD’s support for engineering, which fell 26 percent between 2001 and 2010. The important question here is not how much more the nation should be investing in engineering versus science, but how it can allocate available resources to ensure that the benefits of the science it funds come back to taxpayers as a return on investment.

**FIGURE 8:** Federal Investments in Basic and Applied Research in Engineering: A Small Fraction of the Total Investment in Sciences
FIGURE 9: Comparison of Federal Investments in Science Education vs. Engineering Education (in millions of dollars)

- 26% Agency Specific: $883.29
- 30% STEM: $1,023.34
- 41% Science: $1,393.83
- >1% Math: $15.07
- >1% Engineering: $14.13
- 3% Science & Math, Engineering, or Technology: $110.63

FIGURE 10: Decline in Federal Funding of Engineering Research

2005 CONSTANT ($ MILLION)

2001 2011 (prelim)

- All Fields: ▲ 8.1%
- Life Science: ▲ 7.0%
- Math & Computer Science: ▲ 4.3%
- Physical Science: 0%
- Engineering: ▼ 4.3%
Countries like Germany, Japan, South Korea, China and Taiwan, meanwhile, revere engineering, and their governments are leveraging scientific breakthroughs made in the United States to their own advantage by sharing development risks to help get products using those breakthroughs ready for eventual production by private firms.

NATIONAL TECHNOLOGICAL INFRASTRUCTURE I: EDUCATION

Considering that the federal government devotes so little of its STEM funding to engineering, it is hardly surprising that the current K-12 STEM curriculum emphasizes courses in math and science aimed at those bound for four-year colleges while treating as an afterthought “technology” courses that prepare students to go into the trades directly out of high school. What’s more, since they have been educated to place value on analysis and mathematical rigor, modern generations of U.S. engineers tend to think of engineering not as a creative, synthetic field but as an applied-mathematics discipline. According to the U.S. Department of Education, 5.3 percent of all bachelor’s degrees awarded in 2009 in the United States were in engineering. Internationally, the corresponding figure was 18.4 percent.

In Germany, 58 percent of upper-secondary students were enrolled in a vocational or technical training program in 2008. As apprentices, young German workers divide their time between the classroom and hands-on training, receiving a modest stipend from their employers, and even though there is no guarantee that students will stay on permanently, employers are willing to devote significant funding to apprenticeship programs. The electronics giant Siemens spends more than $200 million per year on these training programs, in which over 10,000 young workers participate. In 2012, as a means to address the aging of its workforce, one of its U.S. subsidiaries, Siemens Energy Inc., launched an apprenticeship program at its Charlotte, N.C., gas-turbine plant for local high school students. The company is investing $165,000 to train each apprentice, and all will have jobs waiting for them when they are done.

Challenge-based, hands-on learning can get students excited about careers in engineering, but because engineering is portrayed as a discipline reserved for the mathematically gifted, creative minds are frequently scared off.
The United States needs a revitalized engineering culture that makes explicit the connection between theory and design, thereby providing experiences that can inspire future generations to pursue engineering and manufacturing careers.

To this end, the recent emergence of the “Maker Movement” is having a phenomenal influence on American youth. *Maker Faires* bring together science, art, crafts, engineering and music in fun, energized and exciting public forums. They inspire people of all ages to roll up their sleeves and embrace a do-it-yourself spirit. Making and tinkering is only the first step, of course. Making is not the same as manufacturing, just as tinkering is not engineering.

The number of programs that specifically target students has been increasing. A few examples:

**Project Lead The Way** has been highly successful in bringing hands-on engineering education to high schools across the nation, involving over 400,000 students in all 50 states.

**FIRST Robotics** is an outstanding example of an extracurricular program that has inspired thousands of middle school and high-school students to pursue careers in science and engineering.

**Innovation 101**, a program of the educational nonprofit The Henry Ford in Dearborn, Mich., promotes a culture of innovation by engaging students at all grade levels in hands-on activities that are contextual, experiential, challenging and fun.

**The Society of Manufacturing Engineers** has developed new programs, including computer-integrated manufacturing projects that are intended to inspire youth.

**STIHL**, a manufacturer of handheld outdoor power equipment, last year launched a week-long summer camp in Hampton Roads, Va., that features tours, lectures and manufacturing demonstrations for high school students. Student groups competed on design/build projects, gaining understanding of what it takes to make a product, grow a business and learn about robotics and automation.
These and other such programs need to be brought into the mainstream — into every classroom in every school at all grade levels. Only a new pipeline of talented engineers can keep America at the forefront of innovation.

To encourage its employees, who are already in the manufacturing world, to transform their creative ideas into physical prototypes, Ford Motor Company has invested in TechShop facilities. The Detroit TechShop is a 17,000-square-foot facility stocked with $750,000 worth of laser cutters, 3D printers and CNC machine tools, and staffed with “Dream Consultants” whose job it is to help users fabricate pretty much anything. Ford employees are free to take advantage of the space day or night for projects related to their work or for personal projects.

**NATIONAL TECHNOLOGICAL INFRASTRUCTURE II: RESEARCH**

Other countries have recognized the connection between R&D networks, manufacturing and economic growth, and they have developed policies that promote advanced-manufacturing R&D at home. Germany’s Fraunhofer Institutes and the U.K.’s Innovative Manufacturing Research Centers are specific manufacturing-R&D efforts. Other examples of how nations have included manufacturing R&D as part of a larger scheme to keep innovation within their borders include:

- the European Commission’s Competitiveness and Innovation Framework;
- China’s 2006 policy package, which includes significant measures to support innovation, and its subsequent development of four industry-research strategic alliances;
- Singapore’s investment in public-private research parks such as Biopolis and Fusionopolis;
- Taiwan’s Industrial Technology Research Institute; and
- Japan’s prioritization of science-industry relations and cluster policies, including Technopolis.
That America’s competitor nations have taken such actions makes the case for similar investment here compelling, since the United States no longer has private-sector research laboratories like Xerox PARC or Bell Labs, both of which contributed so much to the nation’s prosperity. Beginning in Thomas Edison’s time, American research institutions united knowledge, skills, resources, infrastructure and leadership, providing a full-service technology-development and commercialization model for the modern age. The scientific discoveries at Bell Labs that led to such inventions as the transistor, the laser, solar cells and satellite communications showed what scientists and engineers can do when they work together: transform scientific breakthroughs — the 1 percent “inspiration” of Edison’s formula for “genius” — into the engineering solutions that arose thanks to the formula’s 99 percent “perspiration.” In a June 2011 report to President Obama titled “Ensuring American Leadership in Advanced Manufacturing,” the President’s Council of Advisors on Science and Technology (PCAST) identified this gap in the U.S. innovation cycle and recommended that the government invest in pre-competitive applied research, i.e., translational R&D. The idea was to establish institutions modeled after Bell Labs and the Fraunhofer Institutes. This led to the establishment of a national network of Manufacturing Innovation Institutes, announced by President Obama in March 2012.

To be sure, the technology innovation pursued by large corporations today is critical to America’s remaining globally competitive, but that’s in the short run. If new industries are to be created, “radical” technological
innovation — innovation that leverages scientific breakthroughs — is needed. The value of “patient capital” and of the resources associated with the Bell Labs of the past is, however, no longer evident to most U.S. corporate managers. The average time investors on Wall Street hold a stock has dropped, dwindling from eight years in the 1960s to only four months in 2012. Although the federal government continues to invest in basic research, which in turn continues generating new ideas and scientific breakthroughs just as it did when the big corporate research institutions were there to develop them, it is now other nations that are picking up the results, capitalizing on U.S. discoveries and inventions and creating value for themselves. Losing those private-sector facilities has significantly impaired America’s innovation ecosystem, impairing its ability to transition good science into U.S.-based manufacturing. If the United States proves unable to find the 21st-century equivalent of those legendary hotbeds of creative industry, it may concede forever its lead in innovation and prosperity.

It is generally acknowledged that the United States has the world’s best higher education, since American universities still dominate the global top-100 list. But if America stands on the top rung of the academic ladder, that ladder may well be leaning against the wrong wall. This is because current university rankings are not based on outcomes but are instead structured mostly on inputs such as standardized test scores, acceptance rates, research expenditures, reputation and alumni donations.

A more useful ranking system would be based on such outcomes as teaching effectiveness, the number of new businesses or industries created and societal impacts on health, national security and energy. It is perfectly conceivable that at least the top 10 to 20 U.S. universities could retain their high ranking even according to such outcome-based criteria. But the vast majority of U.S. universities are mainly driven by how to improve their standing in the annual U.S. News and World Report ranking because a high ranking there brings prestige, which attracts students, faculty members and new funding, both public and private. Even though the federal government measures research outcomes in terms of publications, citations and patents, the taxpayers who fund the research are likely to treat those measures as only intermediate outputs at best.
GERMANY’S FRAUNHOFER INSTITUTES FOR APPLIED RESEARCH

A cornerstone of Germany’s innovation ecosystem is the Fraunhofer Institutes for Applied Research. Established in 1949 as part of the West German government’s effort to rebuild Germany’s pre-war research infrastructure, the non-profit Fraunhofer-Gesellschaft is one of the world’s largest and most successful applied-technology organizations. Fraunhofer’s 80 research institutes and centers, 60 located in Germany and the rest abroad, employ some 20,000 scientists and engineers and train 4,000 Ph.D and master’s students annually. Fraunhofer’s $2.6 billion annual budget comes from Germany’s federal and state governments, manufacturing clients and publicly funded research projects that it wins on a competitive basis from the German government and the European Union. The most closely comparable program in the United States, the NIST Manufacturing Extension Partnership (MEP), has a budget of $125 million, 15 percent of Fraunhofer’s budget.

The Fraunhofer Institutes’ mission is to act as a “technology bridge” connecting basic research and German industry. Although Fraunhofer researchers publish scientific papers and secure patents, having filed 685 patent applications in 2009 alone, their primary mission is to disseminate and commercialize technology. Most of the organization’s remarkable range of applied-research programs — which span microsystems, life sciences, communications, energy, new materials and security — focus on collaborating with German manufacturers to pursue clearly identified market opportunities.

Fraunhofer is growing quickly. Between 2007 and 2012, it added 6,000 researchers to its payroll and its overall budget increased by 29 percent. The institute has helped grow Germany’s economy through an export boom. In 2011, German exports increased by 8.2 percent, helping deliver a 3.0 percent increase in GDP and driving the country’s unemployment rate to its lowest level in 20 years. “We at Fraunhofer have clear research results,” says its president, Hans-Jörg Bullinger. “We have a worldwide recognized model of research and application.”

The 60 installations Fraunhofer runs in Germany collaborate closely with manufacturers in 16 different industry clusters. Fraunhofer Institutes offer
a broad portfolio of services to 5,000 corporate clients, nearly a third of which are small and medium-sized enterprises. The diversity of its funding sources enables Fraunhofer to use different approaches to commercializing technology, one of which is helping develop specific technologies for companies. For example, Schott Solar contracted with Fraunhofer to develop technology for absorber tubes used in solar receivers that are being exported out of Schott’s factory in Albuquerque, N.M.

Recent Fraunhofer lab inventions for industry include touch-controlled organic light-emitting diode lighting, artificial animal tissue for drug testing, lightweight bicycle-seat posts, new steel-cutting techniques for car manufacturers, micro-helicopters and ultra-efficient gem-cutting tools. Fraunhofer earned several hundred million euros from licensing its signal-compression technology for MP3 players, which has been one of its most lucrative lab successes.

In its 2012 annual report, Fraunhofer uses a quote attributed to Charles Darwin to motivate its German manufacturing forces: “It is not the strongest of the species, nor the most intelligent that survives. It is the one that is the fastest and most adaptable to change.”

GOVERNMENT’S ROLE IN THE U.S. INNOVATION ECOSYSTEM

Fortunately, the federal government has a history of fostering innovation in ways other than simply funding basic research. For over a century, the federal government has played an essential role in bringing emerging technologies to market. In cases from aircraft, semiconductors and computers to the Internet and GPS, it is the federal government that has set the wheels in motion to transition promising technologies into products with societal benefits. Though it is fashionable to say that “government should not pick winners and losers” but rather “get out of the way,” the U.S. government has historically enabled the creation of new high-technology industries by underwriting not only basic research but also applied research, development, demonstration and early procurement.

To choose a single but highly significant example, America’s aircraft industry did not spring spontaneously out of the ground the day after Orville Wright took the Flyer airborne at Kitty Hawk. A dozen years after that 1903
maiden flight, the United States was lagging behind other nations in aviation. Then, in 1915, the federal government launched the nation’s first aviation initiative, establishing the National Advisory Committee for Aeronautics to conduct the research and development needed to advance the standards, design and development of engines and airfoils. After producing only 411 aircraft by 1916, American companies churned out more than 12,000 in a nine-month period bridging 1917 and 1918 to support the war effort.

To be sure, it is the genius of individual entrepreneurs and dedicated scientists and engineers that creates the initial spark for new industries, but it sometimes takes the federal government to fund early, high-risk R&D in order to overcome hesitance, and occasionally even opposition, on the part of established firms. When the U.S. Air Force and the Pentagon’s Defense Advanced Research Projects Agency (DARPA) approached AT&T and IBM about getting involved in applied research and demonstration of nascent ideas in networking communications research, the firms were less than enthusiastic for a number of reasons, one being their belief that a major success might threaten their business. So it was DARPA itself that invested in the packet-switching concept of computer pioneer Paul Baran in the early 1960s, and then in the 1969 demonstration of ARPANET, a forerunner of the Internet of today. Without government’s investment in R&D the Internet revolution would not have occurred.

Government procurement has also had a significant impact on accelerating innovation in electronics by lowering the risk of emerging technologies so that they could be scaled in a cost-effective manner. The U.S. Air Force and the National Aeronautics and Space Administration (NASA) bought almost every microchip produced by private firms during the 1960s, which led to the creation of production lines capable of putting out large quantities of chips quickly and cheaply. Within a span of a few years, the price dropped by 98 percent, from $1,000 per unit to about $20 per unit.

By co-investing in pre-competitive R&D to mature emerging technologies both through public-private partnerships and through a coordinated, strategic approach to procurement, government has aided as well as encouraged U.S. firms to fill in the gap between basic research and advanced manufacturing.
Developing and assessing the scalability, reliability and cost-effectiveness of promising early-stage technologies requires both patience and capital. The federal government, in its role as funder of public goods, should invest in promising “platform” or generic technologies that can enable the development of a large variety of products further downstream. The private sector chronically underinvests in such “pre-competitive” technologies, daunted by market, financial and technological risks and by the fact that a single firm, or even an entire industry, can seldom reap a large enough share of the benefit to justify such an investment. Rather than going it alone and absorbing all the costs, however, government can engage industry in public-private partnerships structured as consortia that can enable maturation of emerging technologies and their manufacturing readiness, enhancing U.S. manufacturing competitiveness.

When the U.S. semiconductor industry lost a considerable portion of its market share to Japan in the 1980s, 14 U.S.-based semiconductor manufacturers came together with the federal government to form the Semiconductor Manufacturing Technology (Sematech) consortium. With total federal funding of $500 million for its first five years — a lot of money at the time — Sematech focused on conducting translational R&D in the field of advanced semiconductor manufacturing. It was instrumental in America’s regaining its competitiveness.

Today the United States has significant opportunities to capture the fruits of its investments in basic research in areas like nanotechnology, flexible electronics, photonics, lightweight structures, next-generation robotics, IT-enabled smart manufacturing and biofuels. Basic research shows, for example, that electronic circuits can be printed roll-to-roll on flexible substrates. But there are numerous research and technology challenges that must be addressed — material degradation, encapsulation, feature size and resolution, to name a few — before flexible printed electronics can become practical. This is an example of an excellent occasion for pooling private and government investment, as large-scale roll-to-roll manufacturing of electronics, once matured, would create a platform to launch entirely new products across multiple sectors, including inexpensive flexible solar cells, displays, lighting, smart bandages, sensors and flexible batteries.
If the United States is to build an “industrial commons” and promote innovation-based manufacturing at home, it may take both government and private-sector participation in infrastructure investments like those needed to nurture the knowledge base, acquire the skills and build the equipment that provides the foundation for roll-to-roll platform technology. This is but one small example of the potential that exists to revive the American economy.

NATIONAL SECURITY IMPLICATIONS

It would have been worse had the Kindle been a defense-critical item. A recent investigation by the Senate Armed Services Committee (SASC) revealed a “flood of counterfeit electronic parts coming into the Defense Department’s supply system.” The committee’s final report, released in May 2012, outlined more than 1,800 cases of suspected counterfeits involving more than 1 million parts for use in some of the country’s “most important military systems.”

When committee staff started digging into the question, they found all types of shady Chinese suppliers, including, for example, Hong Dark Electronic Trade of Shenzhen, a company that sold 84,000 counterfeit electronic parts into the Pentagon’s supply chain. Senate investigators found that the military version of the Boeing 737 commercial airliner, the Poseidon P8-A aircraft, was riddled with illegal Chinese electronic parts supplied to Boeing by BAE Systems, Honeywell, L3 Communications Systems and Rockwell Collins. The same fake parts may be on the commercial Boeing jetliner, but the SASC staff couldn’t say for sure. It’s not clear how many of the parts cited in the report could be manufactured in the United States.

CORPORATE R&D

Today, only 4 percent of private-sector R&D in the United States is targeted at basic research; as noted above, most R&D spending by industrial companies is on applied research and is devoted almost entirely to product development and incremental process innovation. U.S. manufacturing sectors that devote large percentages of their sales to R&D are communication equipment (14.7 percent), pharmaceuticals (12.7 percent) and semiconductor equipment (12 percent). R&D-intensive industries typically
have R&D-to-sales ratios greater than 3 percent. But the United States has slipped behind Japan, South Korea and Germany in its share of R&D-intensive industries.

**Figure 12: Percentage of Manufacturing Sector with 3 Percent or Greater R&D Intensity**

Companies’ investments in R&D often create spillover benefits, many of which go to other companies, especially if they are clustered in regional high-tech centers of excellence. However, spillover benefits of U.S. public investment in science, advanced tools and new technologies are now being reaped more than ever by non-U.S. entities. China is the leading exporter of advanced-technology products to the United States, surpassing all of Europe combined, yet not a single publicly traded Chinese company is on the list of the world’s top 100 R&D spenders.

Of the 57 major global telecommunications R&D announcements in 2011, more than 60 percent came from Asia, compared to 9 percent from the United States. Intel, which has invested approximately $1 billion in research in India, in 2008 unveiled the first microprocessor designed entirely in that country, which was also the first 45-nanometer chip to be designed outside the United States. Because U.S.-based manufacturing
firms’ offshore R&D investments grew more than three times as fast as their domestic R&D investments between 1999 and 2007, the prospects for a robust period of growth for the U.S. economy have been further diminished.

GLOBALIZATION OF UNIVERSITY R&D

The same trends hold true for universities. In recent years, U.S. universities looking for new ways to grow have established satellite campuses in other countries. As of 2010, 38 American universities had 65 branches in 34 countries whose most popular programs are in the sciences, engineering and business. But the trend of attracting additional hefty tuition dollars from foreign students has gone beyond educational missions. A growing number of research universities in the United States have established overseas satellite research labs — some far more advanced than those at the home institutions — lured by massive investments by host countries eager to capture the “secret sauce” of American innovation. As host countries spend lavishly on scaling American inventions into commercial products, the knowledge, skills and infrastructure needed for the next generation of innovation begin to take root, raising more questions about the benefits U.S. taxpayers are gaining from the investments they are making in academic research.

INTELLECTUAL PROPERTY AND TECHNOLOGY COMMERCIALIZATION

The Association of University Technology Managers reports that from 2005 to 2009 its university members received $142 billion in federally funded R&D and presented over 85,000 invention disclosures. More than 53,000 patent applications based on those disclosures were submitted to the U.S. Patent and Trademark Office, with only 15,000 being granted a U.S. patent. That represents less than an 18 percent return on the total number of disclosures. During that five-year period, there were only 3,781 licenses executed with the private sector and 2,532 companies that spun out of these same universities. Considering the funding commitment, American taxpayers are not getting much of a return on their investment in university research.
**Figure 13:** Invention Disclosures, Patent Applications, Licenses and Start-Ups Resulting from Research Conducted at U.S. Universities and Federal Labs.

**Aggregate Invention Disclosures, Patent Applications, Patents Issued, Licenses and Start-Ups (U.S. Universities)**

**Aggregate Invention Disclosures, Patent Applications, Patents Issued and Licenses (Federal Labs)**
Nearly three decades after the passage of the Bayh-Dole Act, which promotes academic technology transfer, it has finally been widely recognized that university research rarely results in the creation of billion-dollar industries right out of the gate; further investments in technology maturation are needed. Many university technology-transfer offices across the nation are making aggressive efforts to license their intellectual property to private entities. But most of the technologies are not ready for prime time, as it requires years of design, development and testing to take an invention and turn it into a product that can be produced cost-effectively at scale. Universities commonly engage interested parties in complex legal agreements only to discover a few years later that all the effort had yielded little in the way of a practical product and the accompanying royalties they had hoped for. A new model is needed for commercializing university R&D that simplifies licensing agreements and provides companies with a grace period on paying royalties on technologies developed with federal funding. Also under this new model, products based on technology developed by universities with U.S.-government funds should be required to be produced in the United States.

REGAINING AMERICA’S COMPARATIVE ADVANTAGE

Innovation-driven manufacturing, the United States’ traditional comparative advantage, relies on advanced technologies conceived and developed by top-flight scientists and engineers and subsequently manufactured with high productivity by a skilled workforce. It is by closing the innovation gap — the “missing middle” between research and entrepreneurship, where practical know-how fuels application — that America can regain its comparative advantage. This means focusing on the engineering required to convert scientific knowledge into new products, processes and industries that are rooted in the United States and that alone can eliminate the trade deficit in advanced-technology products.

As noted by Ralph Gomory, former director of research at IBM and president emeritus of the Alfred P. Sloan Foundation, goods production is indispensable for a healthy national economy. “Balancing trade on ideas and R&D simply cannot be done,” he has written. “It is really wrong to think that you can scale up R&D to be big enough so we can trade it for
the huge quantities of things we need but don’t make in this country.”34 What will be required is an investment in translational research, accompanied by a new generation of engineers and skilled workers who are passionate about creating and working with new products and processes.

INSPIRING FUTURE ENGINEERS AND SKILLED WORKERS

While U.S. high schools commonly require students to dissect a frog, hardly any require students to disassemble a power tool. No matter their age, giving students the skills to take things like power tools or kitchen appliances apart can engage them in design, materials, manufacturing and safety challenges by tapping into the curiosity and creativity that many children naturally have. In the past, talented mechanics and passionate engineers grew up repairing farm machinery or fixing their own car, but today fewer kids are growing up on farms, and it takes a high-end computer and a trained technician to diagnose, let alone repair, an automobile. It is, therefore, critical that K-12 students be provided with opportunities to see how things work, why they don’t always work the first time and how they can be improved and perfected. It is simply impossible to get that experience, and to be inspired by it, any way other than through practice.

America needs to attract to engineering those students who are passionate about innovation, invention and entrepreneurship, and those who dream of devices that can change the world for the better. Just 4 percent of U.S. high-school graduates pursue engineering, compared to 10 percent in Canada, 15 percent in Germany and 25 percent in China. Only when the United States starts to generate a new pipeline of talented engineers and skilled production workers will the country regain its position at the forefront of innovation and high-tech manufacturing.

OBAMA ADMINISTRATION INITIATIVES IN ADVANCED MANUFACTURING

President Obama has publicly recognized the vital importance of manufacturing to America’s economic future on several occasions, one of them being the announcement of the Advanced Manufacturing Partnership35
in 2011. Manufacturing is the lead-off topic in “Blueprint for An America Built To Last,” a White House document that encapsulates points made by the President in his 2012 State of the Union address. The administration, to its credit, is supporting a number of initiatives promoting advanced manufacturing, technology transition, entrepreneurship and access to development capital. Among them are:

- An Advanced Manufacturing Partnership with a $1 billion proposed investment to establish a national network of Institutes for Manufacturing Innovation, an idea put forward in PCAST’s June 2011 report on advanced manufacturing. These institutes will be public-private partnerships aimed at maturing technologies and manufacturing readiness, with each addressing pre-competitive applied research and encouraging the establishment of shared facilities. The institutes are modeled after Germany’s Fraunhofer Institutes and will focus on product and process innovation. This is an important step in the right direction, coming after Washington had ignored the manufacturing sector for over a decade. A $35 million pilot institute specializing in additive manufacturing was created in Youngstown, Ohio, in August 2012;

- Investment in new Manufacturing Demonstration Facilities by the Advanced Manufacturing Office in the Office of Energy Efficiency & Renewable Energy at the Department of Energy (DOE);

- Investment by DARPA in new manufacturing initiatives aimed at reducing product-development time and cost (the latter by a factor of five);

- The National Robotics Initiative, a multi-agency initiative funded by NASA, NSF, the National Institutes of Health and the Department of Agriculture whose goal is to develop a new generation of robots to work alongside humans;

- Proof-of-concept centers, funded by NSF, to be located throughout the country with the aim of promoting translational research, entrepreneurship and the innovation ecosystem at American universities;

- NSF’s Innovation Corps, a public-private partnership providing help from successful entrepreneurs and business leaders, in addition to
funding, to researchers with the aim of transitioning ideas from basic research to the marketplace;

- The Economic Development Administration’s i6-Challenge Grants, which have established over a dozen regional innovation clusters and proof-of-concept centers to promote technology-based economic development;

- More than 150 challenges inspired by X-Prize competitions, through which more than 40 federal agencies are seeking out citizen-innovators to solve societal challenges ranging from advancing vehicle designs to combating Type-2 diabetes and forecasting solar activity; and

- The Right Skills Now program, whose goals include training 500,000 workers over five years in much-needed manufacturing skills like computer numerical control machining and welding. The endeavor is a partnership of the Obama administration’s Jobs Council, the National Association of Manufacturers’ Manufacturing Institute, the National Institute for Metalworking Skills and the Society of Manufacturing Engineers.

In addition, the Obama administration has pledged resources and attention to enhancing the competitiveness of the country’s small and medium-sized manufacturers (SMMS) by providing easy access to 21st-century digital design and manufacturing tools. America’s nearly 300,000 SMMS form the backbone of its industrial economy, contributing more than 50 percent of the nation’s manufacturing GDP and employment. SMMS provide the core supply-chain infrastructure that is critical to developing and scaling new technologies and manufacturing processes, and they are less likely than large manufacturers to move their operations offshore.

**COORDINATED AND STRATEGIC INVESTMENTS IN U.S. MANUFACTURING R&D**

Given the significance of the manufacturing sector to its economy and national security, it is critical that the United States establish a permanent office to develop and implement policies aimed at ensuring coordination of investments with the private sector. In 2010, the White House Office
of Science and Technology Policy established an interagency Committee on Advanced Manufacturing under the auspices of the National Science and Technology Council, which released a report in 2012 outlining a national strategy for advanced manufacturing. Aside from this recent effort, there is no formal coordination of manufacturing investment across the federal government, spending is widely diffused across agencies and even the definition of “manufacturing research” varies from program to program and agency to agency. Federal R&D investments in such areas as agriculture, defense, energy and health care are at least administered separately by agencies that are dedicated to those sectors – although no formal mechanisms are in place to coordinate and leverage the different agencies’ research findings. Because manufacturing cuts across multiple sectors, from chemicals and energy to medical and transportation equipment, it is difficult to identify research synergies and to avoid duplicative activities. Yet because technological breakthroughs spill across multiple fields of manufacturing, coordination of R&D investment that could benefit manufacturing is all the more compelling.

In the current budget climate, it is especially important to leverage the resources and unique strengths of the many agencies whose activities may have a bearing on manufacturing in order to reduce overall costs and to ensure a pipeline for innovation. In addition, a coordinated approach is essential to ensuring that a breakthrough emerging from one agency is handed over to the agency or agencies best suited to carrying it to the next phase of development. It was in spite of a lack of coordination across federal agencies that NSF-funded research eventually led to the development and commercialization of MRI machines, rapid-prototyping machines and Google.

As an alternative, a non-mission-oriented agency like NSF might want to coordinate with the NIST and perhaps with a relevant mission agency like NASA, DOE or DOD on the development path for a scientific
breakthrough arising from one of its grants. If the technology continued to show promise for scaling, early adoption might then be coordinated with a government procurement office. Only through a strategic and coordinated approach to R&D investment can the nation fully reap the benefits of its investment in basic research.

A PROPOSED NATIONAL INNOVATION FOUNDATION

Real innovation requires a marathon relay in which federal agencies hand off their best outcomes to one another while progressing toward the same finish line — rather than engaging in a 100-meter sprint in different directions. The United States needs a whole-government approach that leverages the strengths and missions of different agencies to ensure that the development of promising discoveries and inventions made here is not left to chance or passively allowed to take root elsewhere. America needs to innovate — not just invent — at home, aided by the collective focus of multiple government agencies on creating conditions that will help anchor the manufacturing of each successive “next big thing.” This requires creation of a new agency, the National Innovation Foundation (NIF).

One way to create a NIF without increasing federal expenditures would be by consolidating various existing programs. For instance, NSF’s Engineering Directorate could serve to advance the basic-research component of advanced-manufacturing R&D entirely through open-solicitation and extramural research. The translational research component of a NIF — which would support public-private partnerships dedicated to pre-competitive R&D — could be created by melding appropriate elements of NIST, DOE’s Advanced Manufacturing Office and some elements of the DOD Research & Engineering Enterprise, including the Manufacturing and Industrial Base Policy Office. A NIF should also include the Commerce Department’s Trade Adjustment Assistance for Firms program and the Manufacturing Extension Partnership (MEP) Technical Assistance Program at NIST.
FIGURE 14: Establishing a National Innovation Foundation by Merging Various Existing Uncoordinated Federal Programs in Advanced Manufacturing.
The NIF should align its funding and programs under a strategic framework designed to advance specific goals, such as:

1. Enhancing the competitiveness of SMMs by democratizing the use of shared facilities, computational tools and access to emerging technologies;

2. Closing the innovation gap between basic science and manufacturing through a network of National Manufacturing Innovation Institutes48 (as proposed in the Obama administration’s budget for the fiscal year 2013);

3. Supporting translational research by transitioning to the marketplace scientific breakthroughs made by other agencies, including NSF, DOE, DOD, NASA and the Department of Agriculture;

4. Supporting engineering education at the K-12, community-college and university levels;

5. Establishing and disseminating best practices in product and process development49 to the defense and non-defense industrial bases;

6. Accelerating innovation by supporting early adoption of emerging technologies for government procurement, both defense and non-defense;

7. Providing trade assistance to all industry sectors and ensuring a level playing field for U.S. manufacturers; and

8. Leveraging early procurement of emerging technologies by the DOD to accelerate innovation and to promote the development of advanced civilian technologies.

**LEVERAGING GOVERNMENT PROCUREMENT**

DOD purchases more than $200 billion in manufactured goods every year. There are about 30,000 American SMMs engaged in the U.S. defense supply chain, plus another 10,000 foreign suppliers, but DOD needs to make a concerted effort to expand its pool of domestic suppliers.50

DARPA, which is DOD’s premier research agency, has funded many technological breakthroughs, the Internet and GPS among them.
No one familiar with DARPA should be surprised that it has developed other new technologies since, but it is not as clear how many of these inventions have been transitioned to the military services. Stronger coordination between emerging technologies and defense needs is necessary to transition and scale new advanced-technology products. It would be particularly troublesome, and perhaps strategically dangerous, if products based on technologies painstakingly developed with DARPA funding ended up being manufactured in other countries.51

Although ensuring economic security and manufacturing-job growth at home is understandably not its focus, the Pentagon could make a significant impact both on these and on U.S. technological innovation as well by linking technology development to defense procurement. This is not a new idea by any means; DOD has done it before to prop up the aircraft and semiconductor industries, among others. But there remains no formal coordination between the technology-development process and procurement needs.

**CHALLENGES AND OPPORTUNITIES GOING FORWARD**

**Challenge 1: Legislation That Helps Anchor Advanced Manufacturing in the United States**

Establishing a network of National Manufacturing Innovation Institutes along with a NIF as described above would be an important first step. But while such efforts could bridge the gap between basic research and manufacturing via coordinated technology development, there is still no guarantee that actual manufacturing of new products and processes resulting from new technologies would take root in America. Without legislation that strongly encourages domestic manufacturing while discouraging offshore manufacturing, U.S. investments in science will not benefit the nation’s economic and national security.

Smart legislation offering concrete incentives for establishing new domestic manufacturing facilities and equally concrete disincentives to locating overseas could go far toward ensuring U.S. taxpayers a return on the extensive investments they have made in technology development.
Among the incentives that might be used to help anchor manufacturing in the United States are loan guarantees and a policy of early adoption by the public sector of technologies matured through federally funded programs and public-private partnerships. In cases where firms prefer to manufacture outside the country, they could do so only if they returned to U.S. taxpayers a certain percentage of the profits gained from the offshore manufacture of systems or components employing government-funded technologies or their derivatives.

Challenge 2: Revitalizing American Ingenuity with a Focus on Rebuilding an Engineering Economy

To regain its comparative advantage in high-technology products and rebuild the highly productive and highly skilled workforce that turned them out, America must rebrand engineering, promote the “E” in STEM education at the K-12 level, restore the balance between theory and practice in higher-level engineering education and establish a single, strong voice for engineering in the sphere of public policy.

Rebranding Engineering — It is critically important to reestablish engineering as a creative discipline that contributes huge value to American society. Universities, primary and secondary schools, the private sector and federal agencies should all promote the marvels of engineering culture through easy-to-understand media so as to engage and inspire citizens of all ages.

Promoting Early Engineering Education — Stellar programs like FIRST Robotics and Project Lead The Way, along with the Maker Faires, can play a major role in transforming engineering into something that is engaging and inspiring to kids. It is important to mainstream such activities by including engineering courses in K-12 education. In addition, the private sector should offer manufacturing internships to high-school students and paid apprenticeships to students in community and four-year colleges. Doing this would inspire youth toward more broad-based careers in engineering and serve as a recruitment tool for sponsoring companies. Since many students exposed to engineering through summer camps subsequently consider a career in engineering, engineering societies and universities should actively engage in administering and scaling up such camp experiences.
Striking a Balance Between Theory and Practice — The private sector, nonprofit foundations, universities and other organizations have outstanding programs in place to promote innovation and entrepreneurship and to nurture a pipeline of skilled workers at all levels. Their best practices must be embraced and scaled up to make them effective nationwide. Among these programs’ sponsors are:

- The Deshpande Center for Technological Innovation at MIT, which has awarded grants since 2002 to fund proof-of-concept exploration and validation for emerging technologies. Successful projects from the center have attracted hundreds of millions of dollars in additional investment;
- Stanford University, the University of California at Berkeley, Georgia Tech, the University of Michigan and other schools, which have launched successful programs dovetailing hands-on projects with courses in preparing business plans and entrepreneurship;
- Olin College, which focuses on engineering as a creative discipline and prepares students to be innovators. Twenty-five percent of its graduates are now involved in start-up entrepreneurial enterprises; and
- Kettering University in Flint, Mich., which has had nearly 100 years of experience balancing classroom learning with industrial internships for all of its engineering graduates. With over 600 industrial relationships, Kettering rotates about 1,000 engineering students to industry every semester.

More universities should focus on restoring the balance between theory and practice and on promoting hands-on engineering and entrepreneurship projects that keep that balance.

Public Policy — Public policy significantly impacts everyday life and economic well-being because it sets societal goals and determines the resources that will be allocated to achieving them. For more than a century, the U.S. federal government has played an instrumental role not only in seeding and developing technologies, but also in bringing them to market. From railroad and aerospace development to computers, the Internet and GPS, public investments have provided critical support for basic and applied research. The government has helped establish
shared facilities for conducting cutting-edge research and has served as an early adopter of new technologies so as to help the private sector hone manufacturing processes before entering commercial markets.

It is therefore important for the engineering community to educate the public at large and policy makers in particular about the significance of engineering in technology development and the urgency of investing in the intellectual and physical infrastructure America needs to regain its comparative advantage. Unfortunately, there is no single voice representing the field of engineering, a discipline that has a crucial role to play in closing the nation’s innovation gap. Instead, there are 32 different engineering societies, each representing a specific sub-discipline. Although the American Society of Mechanical Engineers has a long track record of leadership in public policy, it is important for the engineering community at large to present a unified, strong and effective voice that can influence public policy and engage the public imagination.

CONCLUSION

Being the world’s best in scientific discovery is still vital to America’s success, but it is no longer sufficient for maintaining competitiveness in the global economy. The United States must close its innovation gap by:

• investing in translational research in a strategic and coordinated way through a new National Innovation Foundation;
• implementing policies that help anchor manufacturing of advanced-technology products at home; and
• focusing on research and education in real-world engineering.

It is critically important that both policy makers and citizens understand the importance of investing in engineering to confront the challenges that face the nation. The United States’ economy must remain vibrant, diverse and flexible in a world that continues to challenge it to be great, helpful and strong. A new, engineering-friendly economy that values both research and development can become the basis for American prosperity. And Americans need to rediscover the value of their birthright as pioneers and inventors of the future, as the world is in need of both.


3. The U.S. Census Bureau explains its definition of Advanced Technology Products as follows: “About 500 of some 22,000 commodity classification codes used in reporting U.S. merchandise trade are identified as ‘advanced technology’ codes and they meet the following criteria:
   - The code contains products whose technology is from a recognized high technology field (e.g., biotechnology).
   - These products represent leading edge technology in that field.
   - Such products constitute a significant part of all items covered in the selected classification code.

   “This product and commodity-based measure of advanced technology differs from broader NAICS industry-based measures which include all goods produced by a particular industry group, regardless of the level of technology embodied in the goods. ATP classifications are assigned by the Foreign Trade Division of the U.S. Census Bureau.” https://www.census.gov/foreign-trade/reference/definitions/index.html.


9. The manufacturing sector still accounts for two-thirds of America’s R&D, employing about 64 percent of its scientists and engineers.


16. In fact, the National Science Foundation’s Engineering Directorate showcases “engineering discoveries” but not engineering inventions. Many engineering-research organizations and programs have even added the word “science” to their titles to garner prestige. Purpose-driven engineering R&D, the culture of engineering, and even the term “engineering” are slowly disappearing from the U.S. science and technology lexicon.


http://www.epsrc.ac.uk/ResearchFunding/Programmes/BetterExploitation/IMRCs/default.htm.


OECD Reviews of Innovation Policy: China (2009) http://www.oecd.org/document/44/0,3343, en_2649_34273_41204780_1_1_1_1,00.html.


It should be noted, however, that “radical” or “disruptive” innovation did not cease in the United States with the demise of the big corporate laboratory. Rather, it has become the province of the startup company. Typically the outgrowth of basic research, disruptive technologies can be risky technically, require a good deal of time and resources to develop and often ultimately fail to make it into a lucrative market. Although larger firms typically shy away from initial investment in disruptive technologies because of the risk involved and the possibility that they will be unable to capture all the benefits for themselves, they often get access to game-changing technologies by acquiring the startups that developed them. Still, a large firm may need to invest significantly to insert an acquired technology into its products or processes before it can bring them to the marketplace.

From a pure research and scientific discovery point of view, the U.S. is still ahead of most (if not all) other countries.

For a history of the organization, see 60 Years of Fraunhofer-Gesellschaft, Munich: Fraunhofer-Gesellschaft, 2009. The publication can be accessed at http://www.germaninnovation.org/shared/content/documents/60YearsofFraunhoferGesellschaft.pdf.

Presentation by Roland Schindler, executive director of Fraunhofer, in *Meeting Global Challenges: U.S.-German Innovation Policy*.

Explanations of these are examples are found in the Fraunhofer-Gesellschaft 2009 annual report.


http://www.whitehouse.gov/blog/2012/04/30/made-america-helping-revitalize-us-manufacturing.
38. http://www.whitehouse.gov/sites/default/files/microsites/ostp/adv_man_press_release_final.pdf,

39. See fn 22, supra.


44. Additionally, budget strains make establishing a clear correlation between research outcomes and the creation of private-sector jobs in the United States essential to justifying continued funding of federal agencies and labs.

45. Identifying cross-sector applications is generally up to the individual investigator, who must then have the motivation and entrepreneurial spirit to push development. That most programs shy away from funding translational R&D makes success particularly elusive.

46. Robert Atkinson of the Information Technology Innovation Foundation and Howard Wial of Brookings Institution proposed the formation of a National Innovation Foundation within the Department of Commerce to catalyze industry-university partnerships that would promote technology commercialization and entrepreneurship.

47. MEP attempts to enhance competitiveness of SMMs by helping them implement established best practices such as lean manufacturing but is not typically involved in the process of technological innovation.


49. This would go far beyond the scope of what MEP does with lean-manufacturing principles and Six Sigma.


51. Besides, even a commodity product such as a printed-circuit board or something as mundane as a fastener could be designed and manufactured to bring down an aircraft or disable a tank. Such commercial off-the-shelf items are not considered high tech, but trusted sources are critical to the defense supply chain.

52. In this, it could look to the American Association for the Advancement of Science as an example.