REPORT TO THE PRESIDENT ON ENSURING AMERICAN LEADERSHIP IN ADVANCED MANUFACTURING

Executive Office of the President

President's Council of Advisors on Science and Technology

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PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY
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President Barack Obama
The White House
Washington, D.C. 20502

Dear Mr. President,

It is our pleasure to present to you this report, *Ensuring American Leadership in Advanced Manufacturing*, prepared for you by the President's Council of Advisors on Science and Technology (PCAST) and the President's Innovation and Technology Advisory Committee (PITAC). This report provides a strategy and specific recommendations for revitalizing the Nation's leadership in advanced manufacturing.

In preparing this report and its recommendations, PCAST/PITAC held a workshop with leading manufacturing executives and innovation experts. We also consulted experts from your Administration, industry groups, and academia during the course of our study.

Although the U.S. has been the leading producer of manufactured goods for more than 100 years, manufacturing has for decades been declining as a share of GDP and employment. Over the past decade, it has become clear that this decline is not limited to low-technology products, but extends to advanced technologies invented in the U.S., and is not solely due to low-wage competition. Moreover, it is increasingly apparent that technology innovation is closely tied to manufacturing knowledge. We cannot remain the world's engine of innovation without manufacturing activity.

We do not believe that the solution is **industrial policy**, in which government invests in particular companies or sectors. However, we strongly believe that the Nation requires a coherent **innovation policy** to ensure U.S. leadership support new technologies and approaches, and provide the basis for high-quality jobs for Americans in the manufacturing sector.

To ensure that the U.S. attracts manufacturing activity and remains a leader in knowledge production, we recommend the following two strategies: (1) Create a fertile environment for innovation so that the United States provides the overall best environment for business. We believe this can be accomplished through tax and business policy, robust support for basic research, and training and education of a high-skilled workforce; and (2) Invest to overcome market failures, to ensure that new technologies and design methodologies are developed here, and that technology-based enterprises have the infrastructure to flourish here.

We recommend this be accomplished by launching an Advanced Manufacturing Initiative. This initiative would support innovation in advanced manufacturing through applied research programs for promising new technologies, public-private partnerships around broadly-applicable and precompetitive technologies, the creation and dissemination of design methodologies for manufacturing, and shared technology infrastructure to support advances in existing manufacturing industries.

Our report and its recommendations serve the aims outlined in your Strategy for American Innovation, and build upon the initiatives in your 2012 budget proposal. It is an honor to provide our perspective on an issue of such vital importance to the U.S. economy and national security.

John P. Holdren
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The President's Council of Advisors on Science and Technology

Executive Summary

Ensuring American Leadership in Advanced Manufacturing

The United States has long thrived as a result of its ability to manufacture goods and sell them to global markets. Manufacturing activity has supported our economic growth, leading the Nation's exports and employing millions of Americans. The manufacturing sector has also driven knowledge production and innovation in the United States, by supporting two-thirds of private sector research and development and by employing scientists, engineers, and technicians to invent new products and introduce innovations in existing industries.

The Nation's historic leadership in manufacturing, however, is at risk. Manufacturing as a share of national income has declined, as has manufacturing employment, and our leadership in producing and exporting manufactured goods is in question. The loss of U.S. leadership in manufacturing, moreover, is not limited to low-wage jobs in low-tech industries, nor is it limited to our status relative to low-wage nations. The United States is lagging behind in innovation in its manufacturing sector relative to high-wage nations such as Germany and Japan, and has relinquished leadership in high-tech industries that employ highly-skilled workers. Our trade balance in advanced technology manufactured products—long a relative strength of the United States—shifted from surplus to deficit starting in 2001,[1] and a trade deficit of $17 billion in 2003 further widened to $81 billion by 2010.[2] In addition, the United States has been steadily losing the research and development activity linked to manufacturing—and associated high-skilled jobs—to other nations, as well as our ability to compete in the manufacturing of products that were invented and innovated here—from laptop computers to flat panel displays and lithium ion batteries.

As U.S. manufacturing leadership is waning, other nations are investing heavily in growing and revitalizing their manufacturing sectors and are crafting policies to attract and retain production facilities and multinational companies within their borders. Such policies include partnerships, physical structures such as science parks or technology clusters, tax and regulatory incentives, and concentrated investment in commercialization of promising technologies. Some of these policies amount to industrial policy—making clear bets on specific firms and industries—but others support pre-competitive activities that would be regarded as within the scope of appropriate government action in the U.S.

1. The balance of trade for "advanced technology products" has widened since 2002, even with a 25% decline in the dollar relative to an index of major foreign currencies. See Gregory Tassey, "Rationales and Mechanisms for Revitalizing U.S. Manufacturing R&D Strategies," *Journal of Technology Transfer 35* (2010): 283-333.

2. Census Bureau, Foreign Trade Statistics. http://www.census.gov/foreign-trade/Press-Release/ft900_index.html. Data cited by Tassey, G in "Rationale and Mechanisms for Revitalizing U.S. Manufacturing R&D Strategies", December 2009, Figure 1. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.170.3189&rep=rep1&type=pdf

Implications of Declining U.S. Manufacturing Leadership

The future ability of the United States to innovate and invent new products and industries, provide high quality jobs to its citizens, and ensure national security depends upon how well we support innovation and the development and use of advanced technologies for our manufacturing sector.

While the United States may not be able to compete in the long run to make goods for which low-wage unskilled labor is the key input, this need not be true for sophisticated manufacturing linked to products and processes derived from scientific discovery and technological innovation. There are three compelling reasons why we should strive to revitalize our leadership in manufacturing:

1. Manufacturing, based on new technologies including high-precision tools and advanced materials, provides the opportunity for high-quality, good-paying jobs for American workers;
2. A strong manufacturing sector that adapts to and develops new technologies is vital to ensure ongoing U.S. leadership in innovation, because of the synergies created by locating production processes and design processes near to each other; and
3. Domestic manufacturing capabilities using advanced technologies and techniques are vital to national security.

PCAST focuses in this report on **advanced manufacturing**, a family of activities that (a) depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or (b) make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences, for example nanotechnology, chemistry, and biology. This involves both new ways to manufacture existing products, and especially the manufacture of new products emerging from new advanced technologies. We believe that advanced manufacturing provides the path forward to revitalizing U.S. leadership in manufacturing, and will best support economic productivity and ongoing knowledge production and innovation in the Nation.

The Need for an Innovation Policy

While the United States should avoid industrial policy—making bets on particular companies and industries—we should be unabashed in pursuing an innovation policy. Specifically, the Nation requires a strategy for supporting innovation in advanced manufacturing. The objectives of an innovation policy should be to ensure (i) that the U.S. provides the best overall environment in which to do business, (ii) that powerful new technologies are developed here and (iii) that technology-based enterprises have the infrastructure required to flourish here.

A U.S. innovation policy should include creating a business and tax environment that attracts and retains firms that invest in knowledge production and manufacture innovative products here. This can be done via the use of tailored incentives and through improved education and training of our workforce to use and develop advanced technologies. A U.S. innovation policy should also involve building on our Nation's tradition of making strategic co-investments in precompetitive technologies that face market failure but that are critical to innovation in manufacturing. These investments should include support for new technologies that would form the basis of new industries, as well as shared infrastructure facilities that could be accessed by small and medium-sized firms for widespread benefit across industries.

SUMMARY OF KEY CONCLUSIONS

- **The United States is losing leadership in manufacturing—not just in low-tech industries and products and not just due to low-wages abroad. We are losing ground in the production of high-tech products, including those resulting from U.S. innovation and inventions, and in manufacturing-associated research and development (R&D).**
- **As U.S. leadership in manufacturing declines, other nations are investing heavily in advancing their manufacturing leadership, innovation systems, and R&D.**
- **Advanced manufacturing has the potential to create and retain high-quality jobs in the United States.**
- **The Nation's long-term ability to innovate and compete in the global economy greatly benefits from co-location of manufacturing and manufacturing-related R&D activities in the United States. The loss of these activities will undermine our capacity to invent, innovate, and compete in global markets.**
- **A strong advanced manufacturing sector is essential to national security.**
- **The United States lags behind competitor nations in providing the business environment and skilled workforce needed for advanced manufacturing.**
- **Federal investments in new technologies, shared infrastructure, and design tools have been crucial to the birth and growth of major new industries.**
- **Individual companies cannot justify the investment required to fully develop many important new technologies or to create the full infrastructure to support advanced manufacturing. Private investment must be complemented by public investment. Key opportunities to overcome market failures include investing in the advancement of new technologies with transformative potential, supporting shared infrastructure, and accelerating the manufacturing process through targeted support for new methods and approaches.**

Strategy & Recommendations to Ensure U.S. Leadership in Advanced Manufacturing

An overarching strategy to revitalize U.S leadership in advanced manufacturing should involve the following two components:

1. Invest to overcome market failures, to ensure new technologies are developed here and technology-based enterprises have the infrastructure to flourish here. Specifically, the Federal Government should do this by:
   - Supporting applied research programs in new technologies with the potential for transforming impact
   - Co-investing in public-private partnerships (PPPs) to facilitate development of broadly-applicable technologies with transformative potential
   - Supporting the creation and dissemination of powerful design methodologies that dramatically expand the ability of entrepreneurs to design products and processes, and

- Investing in shared technology infrastructure that would help U.S. companies improve their manufacturing.

When co-investing to overcome market failures for key technologies, the following criteria should be applied:

- The technology area has a high potential payoff in employment and output.
- There is a prospect of sustainable competitive advantage for the U.S., including through first-mover advantage.
- Identifiable market failures impede adequate private investment.
- PPPs include industrial partners are willing to co-invest with the government.
- PPPs include some industrial partners with sufficient size to invest at scale in the fruits of the pre-commercial research, as well small and start-up enterprises.
- Investments will help anchor subsequent manufacturing in the United States—for example, through shared labs, pilot plants, technology infrastructure and creation of clusters.
- Shared infrastructure will help existing firms and industries compete globally by increasing the quality and performance of their products

2. Create a fertile environment for innovation here, by:
   - Encouraging firms to locate R&D and manufacturing activities in the U.S. through tax and business policies
   - Supporting a robust basic research enterprise
   - Ensuring a supply of skilled workers, through policies that cultivate and attract high-skilled talent

The key recommendation in this report is that the Federal Government launch an Advanced Manufacturing Initiative (AMI). We recommend that AMI be a concerted, whole-of-government effort, spearheaded by the Department of Commerce, Department of Defense, and Department of Energy and coordinated by the Executive Office of the President (EOP), either through the Office of Science and Technology Policy, National Economic Council, or the office of the Assistant to the President for Manufacturing Policy. The Secretaries of Commerce, Defense, and Energy should assign lead responsibility to an appropriate agency or agencies within the Department—such as National Institute of Standards and Technology (NIST) at Commerce, DARPA at Defense, and ARPA-E or EERE at Energy. It is crucial that this whole-of-government effort be complemented by parallel initiatives in the industry and academia. AMI should develop mechanisms to involve these sectors and to draw on their expertise in identifying technological opportunities. An external advisory board that has access to advanced manufacturing expertise should help guide this work.

The coordinating body of AMI should prepare a biennial report to the President on the most important needs for Federal investments to propel advanced manufacturing in the U.S., including (i) Coordinated Federal support to academia and industry for applied research on new technologies and design methodologies, (ii) Public-private partnerships to advance such technologies through pre-competitive consortia that tackle major-cross-cutting challenges, (iii) Development and dissemination of design methodologies that dramatically decrease the time and lower the barrier for entrepreneurs to make products, (iv) Shared facilities and infrastructure to help small and medium-sized firms improve their products to compete globally. The report should also identify the most pressing technological challenges that merit focused attention for these activities.

AMI should also report on the availability of financing for pilot plants and early-stage activities within these technology areas, and should include an analysis of comparable financing opportunities in other countries and options for providing revenue-neutral financing.

Funds to implement the programs recommended by AMI should be appropriated to the Departments of Commerce, Defense, and Energy to support the most promising opportunities. The funding level should initially be $500 million per year to be allocated across the three agencies as appropriate, rising to $1 billion over four years. Some of these funds may be drawn from existing programs as appropriate.

Below we summarize all of our specific recommendations. Further details can be found in the report.

SUMMARY OF RECOMMENDATIONS

RECOMMENDATION 1: LAUNCH THE ADVANCED MANUFACTURING INITIATIVE

The Federal Government should launch an Advanced Manufacturing Initiative for America's Future (AMI). AMI should be a concerted, whole-of-government effort, spearheaded by the Department of Commerce, Department of Defense, and Department of Energy and coordinated by the Executive Office of the President (EOP).

The coordinating body of AMI should prepare a biennial report to the President on the most important needs for Federal investments, including:

- **Coordinated Federal support to academia and industry for applied research on new technologies and design methodologies**
- **Public-private partnerships (PPPs) to advance such technologies through pre-competitive consortia that tackle major-cross-cutting challenges**
- **Development and dissemination of design methodologies that dramatically decrease the time and lower the barrier for entrepreneurs to make products**
- **Shared facilities and infrastructure to help small and medium-sized firms improve their products to compete globally.**

The report should also identify the most pressing technological challenges that merit focused attention for these activities.

AMI should also report on the availability of financing for pilot plants and early-stage activities within these technology areas.

It is crucial that this whole-of-government effort be complemented by parallel initiatives in the industry and academia. AMI should develop mechanisms to involve these sectors and to draw on their expertise in identifying technological opportunities. An external advisory board that has access to advanced manufacturing expertise should help guide this work.

SUMMARY OF RECOMMENDATIONS (CONTINUED)

Funds to implement the programs recommended by AMI should be appropriated to the Departments of Commerce, Defense, and Energy to support the most promising opportunities, at the level of $500 million rising to $1 billion over four years. Some of these funds may be drawn from existing programs as appropriate.

AMI should work closely with industry and academia in identifying opportunities through an appropriate advisory board.

RECOMMENDATION 2: IMPROVE TAX POLICY

The Federal Government should:

- **Reform corporate income taxes, to bring the marginal tax rate in line with other OECD countries, as advocated by President Obama in his 2011 State of the Union address**
- **Extend the R&D tax credit permanently and increase the rate to 17%, as advocated in the Presidents' Strategy for American Innovation and FY2012 budget request.**

RECOMMENDATION 3: SUPPORT RESEARCH, EDUCATION, AND WORKFORCE TRAINING:

To ensure the health of the research enterprise that underpins innovation and national, and to ensure that the Nation has the highly skilled workforce needed to attract and maintain advanced manufacturing in the United States, the Federal Government should:

- **Fulfill the President's plan to double the research budgets of three key science agencies over the next ten years: the National Science Foundation, the Department of Energy's Office of Science, and the National Institutes of Standards and Technology. Ensure appropriate research budget levels for other research agencies.**
- **Help fulfill the President's goal that public and private investment R&D reach 3% of GDP.**
- **Strengthen science, technology, engineering and mathematics (STEM) education.**
- **Expand the number of high-skilled foreign workers that may be employed by U.S. companies.**

The President's Council of Advisors on Science and Technology

Ensuring American Leadership in Advanced Manufacturing

Executive Report

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I. Current State of U.S. Manufacturing

The United States has long thrived because of its ability to make things and sell them in global markets. Our Nation's leadership in manufacturing has provided a foundation for economic growth, and has employed a large, though diminishing, portion of the work force. The United States was[3] the world's leading producer of manufactured goods from 1895 through 2009; some experts estimate that China surpassed the United States as the leading manufacturing country last year. The manufacturing sector continues to be a mainstay of our economic productivity, generating nearly $1.6 trillion in GDP in 2009 (11.2% of total U.S. GDP).[4] U.S. manufacturing firms lead the Nation in exports: The $1.1 trillion of manufactured goods shipped abroad constituted 86% of all U.S. goods exported in 2010.[5] The manufacturing sector employed 11.5 million workers in 2010, or 9% of total employment,[6] and supported additional non-manufacturing jobs up and down the supply chain as well as in financial services. [7]

Manufacturing has also served as an engine for innovation and knowledge production. Historically, the manufacturing sector has been tightly linked with the nation's R&D activities. Manufacturing firms perform almost two-thirds of all private-sector R&D.[8] Manufacturing companies located in the United States that performed or funded R&D domestically or overseas employed an estimated 16.3 million workers in 2008, and 1.1 million of these were R&D workers (engineers, scientists, technicians and support staff).[9]

Manufacturing is also important in the support of our national and homeland security. The 2010 Quadrennial Defense Review highlighted this, stating "In the mid to long term, it is imperative that we have a robust industrial base with sufficient manufacturing capability and capacity to preserve our technological edge and provide for the reset and recapitalization of our force." [10]

Despite this historic strength, the U.S. manufacturing sector faces enormous challenges, and American leadership and competitiveness in manufacturing is at risk. As a fraction of U.S. GDP, manufacturing declined from 27% in 1957 to about 11% by 2009.[11] Manufacturing employment declined from 17.6 million jobs in 1998 to just 11.6 million jobs at the end of 2010.[12] For decades, we have seen the movement offshore

3. World Industry Service, IHS Global Insight, Inc. Updated: February 17, 2011. This is an estimate of 2010 manufacturing totals that may or may not be confirmed later this year.

4. Bureau of Economic Analysis, GDP-by-Industry-Accounts, Survey of Current Business 2006-2009, January 2011. Available at: http://www.bea.gov/scb/pdf/2011/01January/0111_indy_accts_tables.pdf.

5. International Trade Administration, TradeStats Express, National Trade Data at http://tse.export.gov/TSE/.

6. Bureau of Labor Statistics, Establishment Data, Historical Employment Data, Table B-1. Employees on nonfarm payrolls by major industry sector, 1961 to date: ftp://ftp.bls.gov/pub/suppl/empsit.ceseeb1.txt

7. Joel Popkin and Kathryn Kobe, "Manufacturing Resurgence: A Must for U.S. Prosperity," Washington, DC: National Association of Manufacturers and the NAM Council of Manufacturing Associations, January 2010.

8. Ibid.

9. Francisco Moris and Nirmala Kannankurry, "New Employment Statistics from the 2008 Business R&D and Innovation Survey," *InfoBrief*, Washington, DC: National Science Foundation, July 2010. (Includes U.S. and abroad employment)

10. Department of Defense, *Quadrennial Defense Review Report*, February 2010, p. 103.

11. Bureau of Economic Analysis, GDP-by-Industry-Accounts, Survey of Current Business 2006-2009, January 2011. Available at: http://www.bea.gov/scb/pdf/2011/01January/0111_indy_accts_tables.pdf and http://www.bea.gov/industry/gpotables/gpo_action.cfm

12. Bureau of Labor Statistics, Current Employment Statistics (National), 2010 ftp://ftp.bls.gov/pub/suppl/empsit.ceseeb1.txt, Table B-1. Employees on nonfarm payrolls by major industry sector, 1961 to date: ftp://ftp.bls.gov/pub/suppl/empsit.ceseeb1.txt

of production facilities, a trend that began with furniture, clothing, and textiles, and has expanded to many other commodities.[13] A parallel trend is that average weekly wages in the United States have more or less remained unchanged since 1980, signaling that standards of living have not risen for most Americans over the past 30 years.[14]

The loss of U.S. manufacturing leadership and jobs is not solely an issue of lower relative labor costs abroad. Strong evidence that labor costs are not the key factor is that the United States is lagging behind in driving innovation in manufacturing not just relative to low-wage nations, but also relative to nations such as Germany and Japan. Both countries make high-quality goods that command premiums in the marketplace. In 2003, Germany surpassed the United States in total export value, with key exports in machinery, vehicles, chemicals, and metals and manufactures. (Although in 2009, China surpassed Germany to become the world's leading exporter, Germany still leads the United States.)[15] Moreover, the skills and talents of workers—rather than the cost of labor—appears to matter most to companies deciding where to locate their manufacturing operations: The 2010 Global Manufacturing Competitiveness Index, a study based on the input of 400 CEOs and senior manufacturing executives worldwide, showed access to talented workers was the major driver of a country's competitiveness in attracting manufacturing, above the cost of labor and materials. The report also predicted the U.S. would slip in this competitiveness ranking by 2015.[16] This is despite the fact that BLS data showed in 2007 that U.S. compensation for manufacturing workers was lower than the average for Europe and the rate for 16 other countries.[17]

The loss of U.S. manufacturing jobs is not just limited to commodities, or "low-tech" products. The trend of production migrating abroad has expanded to high-tech manufacturing: The Nation's share of the global market of exports from high-technology industries declined from around 20% in the late 1990s to about 11% in 2008.[18] The trade balance in advanced technology manufactured products—long a relative strength of the United States—shifted from surplus to deficit starting in 2001, [19] and a trade deficit of $17 billion in 2003 further widened to $81 billion by 2010.[20] [See **Figures 1 & 2**.] At the same

13. Ron Hira, "The Globalization of Research, Development and Innovation," in *Manufacturing A Better Future for America*, Ed. Richard McCormack, The Alliance of American Manufacturing, 2009.

14. (In real, inflation-adjusted dollars.) Pisano, Gary P., and Willy C. Shih. "Restoring American Competitiveness." *Harvard Business Review* 87, nos. 7-8 (July - August 2009).

15. Organisation for Economic Co-operation and Development, Main Economic Indicators, International Trade: Exports in goods (value), online at: http://stats.oecd.org/Index.aspx?DataSetCode=MEI_TRD (last accessed Feb 22, 2011). OECD : http://www.oecd-ilibrary.org/finance-and-investment/data/oecd-statistics-on-measuring-globalisation_global-data-en;jsessionid=tpfpgfmyopzx.delta . Export commodities are from the CIA World Fact Book: They provide a listing of the highest-valued exported products, online at. https://www.cia.gov/library/publications/the-world-factbook/fields/2049.html?countryName=Germany&countryCode=gm&regionCode=eu&#gm

16. Deloitte and U.S. Council on Competitiveness - 2010 Global Manufacturing Competitiveness Index, June 2010. Accessible on the web here: www.deloitte.com/globalcompetitiveness The report projects that the U.S. will slip from 4th to 5th place in its ranking for manufacturing competitiveness.

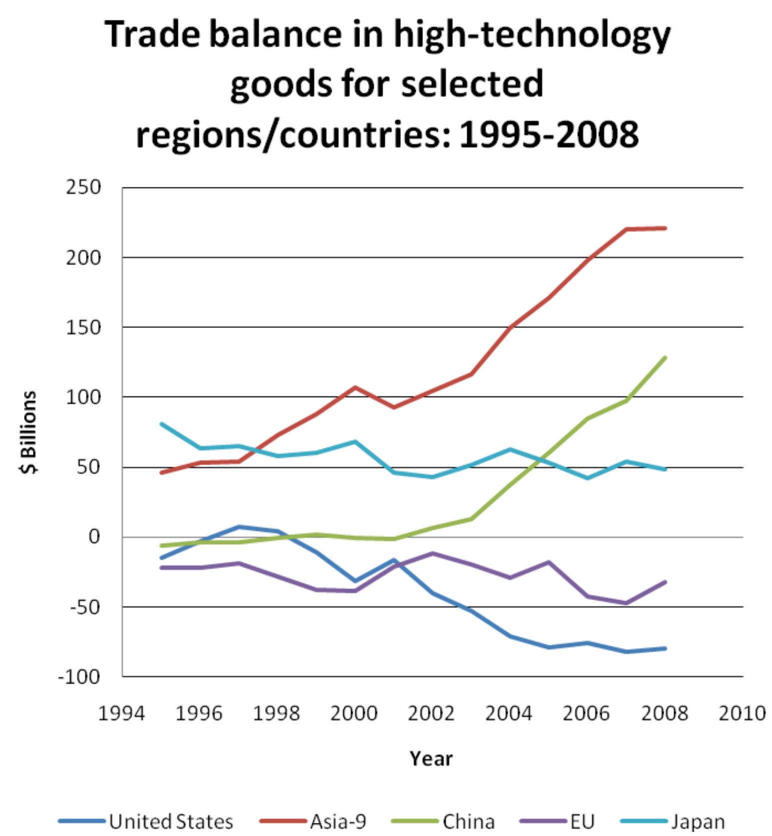
17. Bureau of Labor Statistics, "Production Workers: Hourly compensation costs in U.S. dollars in manufacturing, 34 countries or areas and selected economic groups, 1973–2007," March 2009. (ftp://ftp.bls.gov/pub/special.requests/ForeignLabor/ichccpwsuppt02.txt.

18. National Science Board's *Science and Engineering Indicators 2010.* Appendix Table 6-19, http://www.nsf.gov/statistics/seind10/append/c6/at06-19.pdf, last accessed 2/22/2011

19. The balance of trade for "advanced technology products" has widened since 2002, even with a 25% decline in the dollar relative to an index of major foreign currencies. See Gregory Tassey, "Rationales and Mechanisms for Revitalizing U.S. Manufacturing R&D Strategies," *Journal of Technology Transfer* 35 (2010): 283-333.

20. Census Bureau, Foreign Trade Statistics. http://www.census.gov/foreign-trade/Press-Release/ft900_index.html.

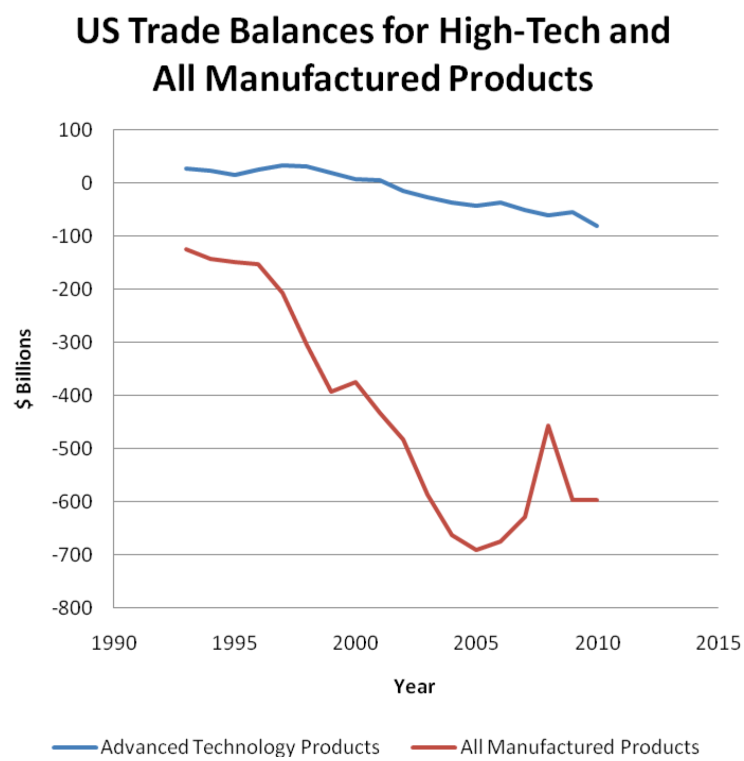
time, China's global trade position in high-technology products moved to surplus starting in 2001, and increased from less than $13 billion in 2003 to almost $130 billion in 2008—led by trade in information and communications goods.[21] We have not simply lost low-value jobs, such as assembly, in the high-tech sector, but sophisticated engineering and advanced manufacturing activities. In addition, we are losing the higher value jobs in software and services. The outsourcing of software development to Indian companies illustrates this progression. At first, companies outsourced basic code-writing projects to Indian firms with lower costs. Now, Indian companies and workers are writing sophisticated firmware, having developed software engineering capabilities.[22]



Source: National Science Board. 2010. Science and Engineering Indicators 2010. Arlington, VA: National Science Foundation (NSB 10-01), Figure O-34

21. National Science Board. *Science and Engineering Indicators 2010* Washington, DC: National Science Foundation. http://www.nsf.gov/statistics/seind10/c6/c6h.htm

22. Pisano, Gary P., and Willy C. Shih. "Restoring American Competitiveness." *Harvard Business Review* 87, nos. 7-8 (July - August 2009).



Source: Census Bureau, Foreign Trade Statistics, FT900: U.S. International Trade in Goods and Services, Exhibit 1s: Exports, Imports, and Balance of Goods by Selected NAICS-based Product Good (Manufacturing, total) and Exhibit 16a (Exhibit 15a for 2009 and earlier): Exports, Imports and Balance of Advanced Technology Products

We are also losing leadership in manufacturing industries based on inventions and knowledge that originated in the United States. Foreign firms now manufacture many products invented here. For example, the United States no longer has the knowledge, skilled people, and supplier infrastructure required to produce light-emitting diodes for energy-efficient illumination, components for consumer electronic products like the Kindle e-reader, or advanced displays for TVs, computers, and handheld devices such as mobile phones.[23] (See **Box 1**.) With respect to batteries, the United States had also lost its lead in manufacturing. (The recent Recovery Act provided $2.4 billion for advanced battery and electric drive component manufacturing, demonstrations, and infrastructure development, which should allow advanced batteries and components for plug-in and hybrid vehicles to be manufactured in the U.S. rather than be imported). Companies in Asia now design nearly every U.S. brand of cell phone and laptop computer, except for Apple.[24] This transfer of knowledge and manufacturing capacity may have national security implications as well, increasing the risk of counterfeit or malicious components in critical security systems. New U.S. companies continue to emerge in new technology sectors, but many keep costs down, access emerging markets and high-skilled workers, and satisfy their investors by locating their facilities abroad, usually in Asia—instead of creating jobs at home. [25]

23. Pisano and Shih, op. cit., p. 3
24. Ibid.
25. Note the details of "Why Amazon's Kindle 2 can't be made in the U.S." in Pisano and Shih, op. cit., p. 3

BOX 1: LOST TECHNOLOGIES

Research and innovation are essential, but alone they do not ensure a successful manufacturing sector. This is a sample[26] of technologies and products with both commercial and defense applications invented in the United States and now produced primarily abroad:

- Laptop computers
- Solar cells
- Semiconductor memory devices
- Semiconductor production equipment such as steppers
- Flat panel displays
- Robotics
- Interactive electronic games
- Lithium-ion batteries

26. List from Tassey, op. cit., p. i

The Nation's loss of manufacturing leadership is not limited to factory jobs; there are also concerns that we are losing leadership in R&D employment and investment related to manufacturing. R&D activity linked to manufacturing is moving offshore to access emerging global markets, and to respond to global competition for talent and the growing supply of scientists and engineers abroad. This is occurring as other countries are increasing their R&D intensities. Over the past several years, spending by U.S. firms on R&D outside the United States has grown at three times the rate of their domestic spending.[27] In the most recent employment statistics from the National Science Foundation's Division of Science Resources Statistics, three industries—all of them in the manufacturing sector—reported U.S. domestic R&D employment as a percentage of worldwide R&D employment as below 70%: communications equipment, semiconductor and other electronic components, and motor vehicles, trailers, and parts. In the last of these industries, domestic R&D employment was only 55% of the global total in 2008. At the same time, many of the nation's approximately 280,000 small and mid-size firms do not have the option to offshore R&D, and struggle to compete with foreign firms.

Put together, these trends makes it increasingly possible to imagine that the United States might be shut out from competing altogether in certain industries as knowledge and inventions are increasingly produced abroad in addition to the products that result from them.

27. National Science Foundation's *Science and Engineering Indicators* 2006 and 2008 and *Research & Development in Industry 2007*. Between 1999 and 2007, foreign R&D funded by U.S. manufacturing firms grew 191% and their funded R&D performed domestically grew 67%, Tassey, op. cit., p. i.

CONCLUSION

The United States is losing leadership in manufacturing—not just in low-tech industries and products and not just due to low-wages abroad. We are losing ground in the production of high-tech products, including those resulting from U.S. innovation and inventions, and in manufacturing-associated R&D.

Yet even as U.S. manufacturing leadership is waning, other nations are investing heavily in growing and revitalizing their manufacturing sectors and are crafting policies to attract and retain production facilities and multinational companies within their borders. Such policies include partnerships, physical structures such as science parks or technology clusters, tax and regulatory incentives, and concentrated investment in commercialization of promising technologies. Some of these policies amount to industrial policy—making clear bets on specific firms and industries, but others support pre-competitive activities that would be regarded as within the scope of appropriate government intervention in the U.S.

The following examples illustrate the international context:

- In terms of R&D investment as a fraction of GDP, the U.S. now ties for 7th in the world behind countries that include Korea, Japan, Switzerland, and Israel. Although the U.S. still accounts for 30% of global R&D, its share is shrinking.
- Unlike the United States, many advanced countries have national agencies that specifically promote technological innovation in their domestic industries, including Denmark, Finland, France, Iceland, Ireland, Japan, the Netherlands, New Zealand, Norway, South Korea, Spain, Sweden, Switzerland, and the United Kingdom. (All these nations also have agencies similar to the National Science Foundation in the U.S. that fund basic research at universities and national laboratories.) The budgets of these national innovation agencies vary widely, but Finland's Tekes invests 560 million USD annually and Japan's New Energy and Industrial Technology Development Organization spends 2 billion USD. [28]
- Other nations are providing far more widespread and ready access to low-cost capital to innovative startup companies, through development banks that finance emerging manufacturing technologies in the clean energy sector and beyond. The China Development Bank, for example, agreed to lend 35.4 billion USD to Chinese wind and solar companies in 2010, compared to the United States' provision of $4 billion in grants and $16 billion in loan guarantees.[29] (The Bank reaped higher profits than Morgan Stanley that year.) China's government bank investment was matched by 54.4 billion USD in state and private investment.

28. Information Technology and Innovation Foundation. *The Good, the Bad, and the Ugly of Innovation Policy: A Policymaker's Guide to Crafting Effective Innovation Policy*. October 2010.

29. Even with private investment, China led the United States. See www.bloomberg.com/news/2011-04-03/china-buries-obama-sputnik-aim-for-clean-power-as-kissinger-advises-bank.html

- Even as China becomes increasingly competitive in making products and using technologies invented in the U.S., it is also producing 300,000 invention patents and about an equal number of "utility-model patents" annually[30] and aims to reach two million in total patent counts by 2015.[31]
- The Industrial Technology Research Institute, Taiwan's major R&D agency, supports 7 research labs and 6 research centers in the country. Through ITRI, the government covers about a fourth of the cost of private sector research in new technology areas. Unlike any U.S. agency, ITRI has the sole mission of developing technology for commercialization purposes. In 2004, it had a budget of $579 million, had spun off more than 100 companies, and had sent 17,000 of its former employees (trained in science and technology) into the Taiwanese workforce.[32]
- Via the Fraunhofer Institutes, Germany's federal and state governments are co-investing with industry in applied manufacturing research. These include private-public partnerships in advanced materials, factory operation and automation, manufacturing and engineering automation, and machine tools and forming technology. The Fraunhofer Production group, which supports adaptive, digital, and high-performance production, has an operational budget of $195 million USD per year.[33]
- Despite the success of U.S. efforts in nanotechnology, which has wide potential for strengthening manufacturing industries, our share of worldwide R&D activity in nanotechnology is declining.[34]
- The Information Technology and Innovation Foundation ranked the U.S. economy last among 40 economies in terms of trends toward improvement in innovative capacity, using a range of criteria including the change over the past decade in corporate R&D, IT investments, foreign direct investment, business climate, and corporate taxes.[35]

CONCLUSION

As U.S. leadership in manufacturing declines, other nations are investing heavily in advancing their manufacturing leadership, innovation systems, and R&D.

30. "Utility-model patents" typically cover items like engineering features in a product and are less ambitious than "invention patents." In the American system, there are no utility patents.

31. From the "National Patent Development Strategy (2011-2020)" published in November 2009 by the State Intellectual Property Office of China, accessed at http://graphics8.nytimes.com/packages/pdf/business/SIPONatPatentDevStrategy.pdf, and cited by Steve Lohr, "When innovation too, is made in China", *New York Times,* January 1, 2011

32. National Research Council. *Innovation Policies for the 21st Century: Report of a Symposium.* 2007.

33. Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, *Annual Report 2009/2010.* http://www.ifam.fraunhofer.de/jahresberichte/jb09/jb2009_en.pdf

34. President's Council of Advisors on Science and Technology. *Report to the President and Congress on the Third Assessment of the National Nanotechnology Initiative,* March 2010. Available at: http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nano-report.pdf

35. See: archive.itif.org/index.php?id=226

II. Implications of Declining U.S. Leadership in Manufacturing

A longstanding debate among economists and policymakers in the United States has centered on whether it matters that we are losing manufacturing industries and jobs. The relative size of the manufacturing sector has decreased substantially in every advanced economy. Some experts observe that it has been the natural course of economic development, as incomes rise and productivity increases, for jobs to migrate from agriculture to manufacturing and from manufacturing to services. In the future, it may be inevitable that the United States will not be able to compete with low-wage nations to make goods for which unskilled labor is the key input. This need not be true for sophisticated manufacturing linked to products and processes derived from scientific discovery and technological innovation. There are three compelling reasons why we should strive to revitalize our leadership in manufacturing:

1. Manufacturing, based on new technologies including high-precision tools and advanced materials, provides the opportunity for high-quality, good-paying jobs for American workers;
2. A strong manufacturing sector that adapts to and develops new technologies is vital to ensure ongoing U.S. leadership in innovation, because of the synergies created by locating production processes and design processes near to each other; and
3. Domestic manufacturing capabilities using advanced technologies and techniques are vital to national security.

In this report, we focus in particular on advanced manufacturing, which we believe offers the path forward for revitalizing manufacturing in the United States. The term refers to a family of activities that (a) depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or (b) make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences, for example nanotechnology, chemistry, and biology. This involves both new ways to manufacture existing products, and especially the manufacture of new products emerging from new advanced technologies.

Advanced Manufacturing Can Provide High-Quality Jobs

Manufacturing already provides good jobs to many American workers, and it has the potential to provide better jobs. Total hourly compensation in the manufacturing sector averages about 22% higher than average compensation in service industries.[36] The "President's Framework for Revitalizing American Manufacturing" notes, however, that wage premiums in manufacturing have been declining for workers with less formal education. Nevertheless, high-technology workers on average earn 50 to 100% more than the average of workers in all other fields.[37] By fostering a more robust high-tech manufacturing

36. From *President's Framework for Revitalizing American Manufacturing:* 40% is due to wages/salaries, 20% due to heath benefits.

37. Hecker, Daniel. "High Technology Employment: A NAICS-based Update," *Monthly Labor Review* (July 2005): 57-72. And "High-Technology Employment: A Broader View," *Monthly Labor Review* (June 1999).

sector and better training our workers, the United States can capture the high-value added jobs involved in the manufacturing of products using advanced technologies and processes.

Companies that are embracing advanced manufacturing techniques and tools, as well as those producing products based on emerging technology, are demonstrating this potential. They are proving that U.S. companies can compete when their products are high-quality, specialized, responsive to customers' needs, and made by workers whose productivity is enhanced through technology and training. Examples include AK Steel, which has flourished in the Rust Belt despite the economic downturn by employing more than 1,300 people to make customized electrical steel for domestic and export markets,[38] and General Electric, which is creating 4,000 manufacturing jobs domestically to make products including energy-efficient washers and dryers, environmental coatings, fluorescent light bulbs, sodium batteries, and jet engines.[39] G.E. is relying on high-tech machinery, skilled workers, and composite materials to create value-added parts for fuel-efficient jet engines in the United States. It is also taking advantage of state and local tax credits, and **automation**, to make energy-efficient washers and dryers in Kentucky. Smaller companies, including Farouk Systems, Inc., a $1 billion hand-held appliance maker, and Emerson, an electrical equipment maker based in St. Louis, have also shifted some production from Asia to the United States to improve quality control and to better access their customers, relying on automation and reduced delivery distance to improve their cost competitiveness.[40] These companies currently represent exceptions to the broader trend of off-shoring of manufacturing.

Further examples suggest that an advanced manufacturing sector can provide a significant number of good jobs. A recent study showed that in New England, there is unrealized potential in advanced manufacturing (defined in the study as the capability to use advanced technologies as the basis of new manufacturing or to improve processes, including precision machining, complex electronics assembly, tooling, prototyping, and engineering-manufacturing collaboration). The report estimated that between 7,500 and 8,500 jobs with the average salary of $80,000 could be created each year in the advanced manufacturing sector in New England if several barriers could be overcome.[41] The barriers include a need for better tax incentives; collaborations across industries, firms, and with government; and better trained workers. Even in Michigan, where overall manufacturing employment has plummeted by more than a third since 2001, the advanced manufacturing sector appears promising. A study of employment in Michigan estimated that 65% (381,000) of the state's manufacturing jobs in 2007 were in the advanced manufacturing sector.[42,43] In 2009, this percent increased to 72% even as the number

38. Stokes, Bruce. "Act II for American Manufacturing?" *National Journal* (December 2010). http://nationaljournal.com/njonline/no_20100508_1960.php/american-manufacturing-s-new-future-is-emerging-but-it-may-need-help-20101209?page=1

39. Lohr, Steve. "G.E. Goes With What It Knows: Making Stutt." *New York Times,* p. BU1 (December 5, 2010). http://www.nytimes.com/2010/12/05/business/05ge.html?src=busln

40. Aeppel, Timothy. "Coming Home: Appliance Maker Drops China to Produce in Texas." *The Wall Street Journal,* p. B1 (August 24, 2009). http://online.wsj.com/article_email/SB125107636394652753-lMyQjAxMTIwNTIxNjAyNzY2Wj.html

41. New England Council and Deloitte Consulting LLP. *Re-examining advanced manufacturing in a networked world: Prospects for a Resurgence in New England.* Dec 2009

42. Anderson Economic Group, LLC. *The University Research Corridor's Support for Advanced Manufacturing in Michigan*. July 2010. Accessible at: urcmich.org/news/100721manufacturing.html

43. The study, however, used a somewhat circular definition of "advanced manufacturing" (i.e., sectors with relatively high-paying jobs, involving the making of high-technology products or developing of processes for future manufacturing, and having productivity growth rates significantly above the U.S. average).

of manufacturing jobs fell in the state; the state lost advanced manufacturing jobs at a lower rate than it lost manufacturing jobs overall.[44]

> **CONCLUSION**
>
> **Advanced manufacturing has the potential to create and retain high-quality jobs in the United States.**

Advanced manufacturing in the U.S. will strengthen innovation in the U.S.

Aside from providing jobs, a strong manufacturing sector is essential if the United States is to remain the world's leader in knowledge production and innovation. Given that manufacturing companies are responsible for about 70% of industrial R&D in the United States, and employ 63% of domestic scientists and engineers,[45] the increasing movement of manufacturing abroad has a direct effect on the innovative capacity of the nation.

Furthermore, when manufacturing migrates offshore so do the knowledge and capabilities that help spur innovative new technologies and allow a country to compete in new industries. Technology and innovation often follow production as it shifts abroad; other countries then gain the knowledge to capture and integrate more of the value in the global supply chain by learning to design products, and then use that knowledge, coupled with R&D, to leapfrog to next generation technologies. When this happens, companies abroad can take advantage of the synergies between design and production to capture market share for new, emerging technologies related to the production of earlier generation technologies. This is the reason, for example, according to Gary Pisano of the Harvard Business School, why the United States lags behind other nations in advanced battery technology for fuel-efficient vehicles. The consumer electronics industry, which shifted to Asia decades ago, demanded and generated the innovations that made batteries lighter and more efficient, and in doing so allowed the nations with that industry to foster manufacturing capabilities for lightweight and rechargeable batteries, including lithium ion batteries. Companies based in countries with those capabilities were better positioned to take advantage of the new market in batteries for electric and hybrid vehicles. Similarly, the capabilities in silicon-processing and thin-film coating that countries such as China, Japan, Korea, and Taiwan developed when semiconductor foundries and flat-panel display manufacturing moved to those countries have helped them to establish leadership in solar panel innovation and manufacturing. The U.S. is not a major player in solar panel technology, in part because of our lack of domestic infrastructure for thin-film and electronics manufacturing. [46]

Proximity is important in fostering innovation. When different aspects of manufacturing—from R&D to production to customer delivery—are located in the same region, they breed efficiencies in knowledge transfer that allow new technologies to develop and businesses to innovate. Historically, the co-location of manufacturing and product design has been vital. Close, rapid feedback between design and pro-

44. U.S. Census Bureau, Local Employment Dynamics. LEHD State of Michigan County Reports. http://lehd.did.census.gov/cgi-bin/qwitop_naicformbrowse?xstate=mi&xstyle=lehd&xntag=31-33&bktag=&xdbase=county

45. Bureau of Economic Analysis, NSF and Wolfe 2009 , as cited by Tassey.

46. Pisano, Gary P., and Willy C. Shih. "Restoring American Competitiveness." *Harvard Business Review 87*, nos. 7-8 (July - August 2009).

duction[47] allows ideas and prototypes to be quickly tested and scaled up, and allows production needs and processes to inform design. Innovation is also aided by interaction between engineers and people working in fabrication. This is because much of the knowledge underlying emerging technologies is tacit, scholars point out, requiring person-to-person contact for efficient information transfer.[48] In modern science-based industries in particular, which are multidisciplinary, innovation requires a range of skilled people from different backgrounds who can communicate effectively. Despite the cross-border, real-time exchanges that information technology has enabled, proximity still encourages people to exchange the knowledge most critical to innovation. For example, engineers in Silicon Valley are more likely to exchange more ideas with other engineers in their region than with engineers on the East Coast.[49]

Harvard professors Gary Pisano and Willy Shih summed up[50] the connection between a nation's loss of manufacturing and its loss of innovative capabilities:

> In reality, there are relatively few high-tech industries where the manufacturing process is not a factor in developing new—especially radically new—products. That's because in most of these industries product and process innovation are intertwined. So the decline of manufacturing in a region sets off a chain reaction. Once manufacturing is outsourced, process-engineering expertise can't be maintained, since it depends on daily interactions with manufacturing. Without process-engineering capabilities, companies find it increasingly difficult to conduct advanced research on next-generation process technologies. Without the ability to develop such new processes, they find they can no longer develop new products. In the long term, then, an economy that lacks an infrastructure for advanced process engineering and manufacturing will lose its ability to innovate.

Our nation's ability to the produce the next generation of inventions and innovations will be greatly enhanced if companies continue to make products here, and to perform R&D here.

CONCLUSION

The Nation's long-term ability to innovate and compete in the global economy greatly benefits from co-location of manufacturing and manufacturing-related R&D activities in the United States. The loss of these activities will undermine our capacity to invent, innovate, and compete in global markets.

47. Ralph Gomory, " The Innovation Delusion," *The Huffington Post*, March 01, 2010
48. Tassey, op. cit., p. i
49. Fleming, Lee, and K. Frenken. "The Evolution of Inventor Networks in the Silicon Valley and Boston Regions." *Advances in Complex Systems* 10, no. 1 (March 2007).
50. Pisano, Gary P., and Willy C. Shih. "Restoring American Competitiveness." *Harvard Business Review* 87, nos. 7-8 (July - August 2009).

Advanced Manufacturing is a Critical National Security Capability

While the national security of the United States benefits from access to many products that are manufactured abroad, ranging from raw materials to technologically advanced components, the irreversible trend toward globalization of supply chains brings with it risks that must be countered by preparedness and appropriate hedging actions. In this regard, a vital advanced manufacturing sector is critical for national defense and homeland security.

A useful perspective on the issue is given in a 2006 National Research Council study[51] commissioned by the Defense Intelligence Agency. That study noted that most scenarios for future conflict involve military action using forces available at the time of the decision to go to war, providing little opportunity for a foreign source to deny necessary material and thereby significantly impact operations, on a tactical timescale. However, on a strategic timescale, the situation is quite different:

> "If the United States were to become strategically dependent on a foreign industrial base for items that are critical or for which the regeneration of a U.S. industrial base would take a long time, the risk would be unacceptable…. [This] possibility should be taken into account when determining what the U.S. industrial base needs to be for defense purposes."

The 2006 committee cites information technology, nanotechnology, and biotechnology as areas worthy of continued vigilance against the possibility of strategic denial.

The capabilities for advanced manufacturing, as described in the present report, are precisely the types of technologies that, if ever lost by the U.S., would take an unacceptably long time to regenerate—if they could be regenerated at all. Thus does advanced manufacturing rise to the level of a critical defense capability.

Furthermore, even in cases that the supply chain risk of foreign suppliers of specific material can be managed (for example, by maintaining multiple suppliers in geopolitically diverse countries), it may be impossible for us to assess risk accurately without the hands-on understanding that can be provided by domestic suppliers of (at least closely related) products. When manufacturing is outsourced, it diminishes not just the capability of producing high-tech goods, but also drains the nation's source of knowledge and talent that would be needed for the reconstitution of domestic capacity, or for a surge capability in time of strategic need.[52]

Because advanced manufacturing will often involve innovative new ideas generated by smaller companies, its advance brings the possibility of broadening the Department of Defense contractor base, yielding more competition and better acquisition outcomes. According to the Department of Defense, past manufacturing programs have been shown to reduce acquisition costs. For example, in a report to Congress, DOD states that implementations of technologies and processes developed by roughly $700 million in manufacturing R&D investment through the Manufacturing Technology Program (ManTech) is projected to result in over $6 billion in acquisition cost avoidance.[53] In 2006, the Defense Science Board

51. Committee on Critical Technology Accessibility, *Critical Technology Accessibility,* National Research Council (2006).

52. Recent events in which China has restricted the supply of rare earth metals illustrate this point, especially if China's goal is to move higher up the manufacturing chain so as to preferentially export advanced manufactured materials (e.g., magnets) made from these rare earth metals. Since such magnets are widely used in U.S. defense systems, strategic denial might become a real possibility, against which the U.S. needs to hedge

53. Department of Defense, *Report to Congress on Implementation of DoD ManTech Projects Receiving FY03 - 05 Funds*, December 2008.

noted that "the need for a cohesive manufacturing research and development investment program is fundamental to rapid acceleration of near term technology capabilities to support warfighting operations and to long-term support for transition of revolutionary technologies."[54]

CONCLUSION

A strong advanced manufacturing sector is essential to national security.

54. Science Board Task Force on The Manufacturing Technology Program: *A Key to Affordably Equipping the Future Force,* p. 1, February 2006.

III. Innovation Policy: Appropriate Roles for the Federal Government

Many other nations are advancing their manufacturing enterprises through policies that include **industrial policy**—that is, direct investment in or subsidies to specific firms. We do not believe that the Federal Government should play the role of a venture capitalist, making large bets on particular firms and industries. Rather, the best industries, firms, and products should thrive based on their ability to compete in the marketplace. [55]

While the United States should avoid industrial policy, the Nation must have a robust **innovation policy**—an approach not of selective cultivation of industries or firms, but of creating the conditions that support innovation in advanced manufacturing.

The objectives of an innovation policy should be to ensure (i) that the U.S. provides the best overall environment in which to do business, (ii) that powerful new technologies are developed here and (iii) that technology-based enterprises have the infrastructure required to flourish here.

Creating a Fertile Environment for Innovation

In the face of abundant global opportunities for the location of both manufacturing and R&D operations, firms seek access to highly trained workers, predictable and favorable regulatory and tax environments, and resources that contribute to innovation.

As other nations invest heavily in attracting manufacturing firms, educating their workforce, strengthening their industries, and promoting innovation, some are providing better conditions—more favorable tax and regulatory environments and better access to talent—to encourage firms to produce goods as well as locate their R&D activities within their borders.

- Many nations offer more attractive tax rates. U.S. average combined marginal corporate income tax rates (Federal, state and local) are 39.21%, higher than in any other OECD nation except Japan at 39.54%. Combined taxes in Germany are 30%, France 34%, Canada 29.5%, and the United Kingdom 28%; smaller countries are much lower (e.g., Chile at 17%, Ireland at 12.5%) and the OECD mean is about 30%.[56] The repatriation of cash generated outside the United States is also subject to domestic taxation to the extent that domestic tax rates exceed foreign tax rates. Business leaders argue that this dissuades companies from putting profits to work at home.[57]

55. It should be noted however, that the U.S. government does provide financing support (through loans and loan guarantees, etc.) for international projects for export-oriented U.S. firms through the Export-Import (Ex-Im) Bank and the Overseas Private Investment Corporation (OPIC).

56. OECD Tax Database, http://www.oecd.org:80/ctp/taxdatabase

57. PCAST notes that corporate tax structures differ across nations, with the result that the actual marginal tax rate for some corporations may differ significantly from the rate in the tax codes; this complicates international comparisons. (See: Kocieniewski, David. "U.S. Business has High Tax Rates but Pays Less," May 2, 2011. http://www.nytimes.com/2011/05/03/business/economy/03rates.html). We also note that it is important to consider the relative merits of lowering marginal tax rates versus providing investment-specific incentives.

- Many nations offer a variety of tax abatements and related inducements to attract manufacturing firms and their R&D operations. The effective R&D tax credit of the United States is now ranked 17th among industrialized nations by the OECD, whereas in 1992 it was ranked first. The R&D tax credit[58] has been temporary since its introduction in 1981, requiring periodic renewal by Congress. This creates uncertainty for businesses, which depend on predictable conditions for long-range planning. President Obama has proposed expanding, simplifying, and making permanent the R&D tax credit in his budget proposal and strategy. This should be implemented as an important first step.
- Worryingly, some nations may offer a more highly-skilled workforce for manufacturing. Access to high-skilled workers, the talent driving innovation, was the single most critical factor determining a country's manufacturing competitiveness, according to a recent report[59] based on the responses of 400 CEOs and senior manufacturing executives from around the world. The report predicted that the United States was likely to decline in manufacturing competitiveness in the next 5 years due to the challenges of accessing such talent. Business leaders at PCAST's workshop reported that US companies are increasingly going abroad because countries such as India, South Korea and China provide the high-skilled workers that they need to advance their R&D enterprise, and to run the advanced manufacturing facilities that produce high-quality, customized products. Business leaders in the United States frequently expressed the view that the nation has a shortage of workers with the skills and knowledge of science, technology, engineering and mathematics (STEM) needed for advanced manufacturing. Business leaders also are concerned that stringent quotas on skilled workers from abroad under the H1-B visa program severely constrain their access to foreign talent.

CONCLUSION

The United States lags behind competitor nations in providing the business environment and skilled workforce needed for advanced manufacturing.

Overcoming Market Failures: Role of U.S. Investment

A major justification for government investments in science and technology is to overcome market failures. Market failures occur when private investors invest less in technology than the socially optimal level, because they cannot reap the full benefits of their investment.

New technologies frequently face market failures. The benefits of early R&D cannot be fully captured by the firm making the investment; instead, many firms or industries benefit from knowledge spillovers. Ironically, the new technologies that have high potential for growth and job creation and that are broadly applicable across several industries, also are technologies where individual private firms often under-invest most (relative to the social optimum) because the benefits of those investments do not

58. The "R&D tax credit" is used in this report to refer to the U.S. Research and Experimentation Tax Credit.
59. Deloitte and U.S. Council on Competitiveness - 2010 Global Manufacturing Competitiveness Index, June 2010. Accessible on the web here: www.deloitte.com/globalcompetitiveness

sufficiently accrue to them in particular, but are shared widely across many firms and industries. For this reason, public investment has been critical in the early stages of R&D.

Historically, Federal technology investment—supporting basic research, funding proof of concept and promoting early commercialization through procurement—has been crucial to the creation of many technologies that have created new industries in the United States. Such investments, commonly supported by the Department of Defense, Department of Energy, National Institutes of Health, NASA, and National Science Foundation, have helped spawn entire industries, hundreds of U.S. companies and millions of high-quality jobs for Americans for decades.

The Internet, for example, was the result of long-term funding from DARPA, and later by NSF. This research was focused not only on basic science, but also on development and demonstrations of technologies such as packet switching, communications protocols, and networking infrastructure. These investments were in areas where the return on invested capital would have been difficult for any single company to capture, and the investments required a long time horizon not easily envisioned by industry leaders.

Significant Federal funding—in some cases paired with industry funding—was also critical for the development of the transistor by Bell Labs in the 1950s, the growth of the semiconductor industry and the birth of Silicon Valley, and to the development of GPS. The Federal government funded in part the major corporate laboratories that laid the foundations for U.S. economic leadership and innovation in the 20th century, including Xerox PARC, RCA David Sarnoff Research Center, and AT&T Bell Labs.[60] According to one study, most of the top annual innovations in the U.S. over the past two decades were supported by a combination of government and industry funding.[61]

The Federal government has also used public-private partnerships as a vehicle to advance key technologies. The SEMATECH consortium of the late 1980s and early 1990s, for example, was a partnership between DARPA and 14 U.S.-based semiconductor manufacturers, in response to the fact that Japan had captured a large portion of the integrated circuit memory chip market, and was poised to capture the majority of that market. This was viewed as a risk to national competitiveness and national security. SEMATECH, which matched $500 million in Federal government spending with equivalent industry spending over 5 years, advanced precompetitive research on the technology needed for next-generation chips. It also funded a test integration facility for tool and equipment suppliers in the semiconductor industry, allowing for prototyping of innovations in chip technology through direct contact between suppliers and the major companies in the consortium.

More recently, the Federal government and industry partners have launched a pilot public-private partnership to advance research on the practical, next-generation computing devices that can replace the conventional semiconductor chip by 2020. The partnership was launched by NIST and the Nanoelectronics Research Initiative (part of the Semiconductor Research Corporation). To date, the partnership has received only modest Federal funding, of about $2.7 million per year, which has leveraged about $20 million in co-investment from the states and industry partners to establish regional research centers. A group of 35 universities in 20 states is contributing to the initiative. With more

60. Tassey, op. cit., p. i.

61. Block, Fred and Keller, Matthew. "Where do Innovations Come From? Transformations in the U.S. National Innovation System, 1970-2006" *Information Technology and Innovation Foundation Report.* July 2008. As recognized by *R&D Magazine*.

significant Federal investment and industry co-investment, this initiative could help advance the critical precompetitive research needed to lead in the future of computing devices.

Finally, we note another option that government can use to make cost-neutral investments that increase access to low-cost capital for innovative technology enterprises that serve national priorities and address societal challenges. Over the long run, private capital markets are efficient at identifying the best technologies; but there can be significant time-lags with early-stage technologies. The experience of some national development banks suggests that co-financing can encourage the transition of promising technologies from the stage of invention to pilot plants for production, while yielding returns for the government. This approach is being increasingly used by other nations.

CONCLUSION

Federal investments in new technologies have been crucial to the birth and growth of major new industries.

The next sections discuss three ways in which Federal Government might help overcome market failures that constrain U.S. leadership in manufacturing and the growth of the advanced manufacturing sector.

Opportunities: Advancing New Technologies

A first way in which the Federal Government can help overcome market failures is to provide support to advance specific early-stage technologies that have transformative potential, but for which rational private actors will under-invest because they cannot capture the full return on their investment, owing to spillover effects that would accrue to many industries and firms.

It is important to distinguish support for specific technology areas versus support for specific technology companies. We do not propose that the Federal Government should play the role of venture capitalist. However, there are appropriate steps that the Government can take to advance key areas, including supporting applied research in promising technologies and precompetitive public-private partnerships and consortia. Such steps are economically justifiable when clear market failures limit progress in technologies with the potential for transformative impact on jobs and output, and sustainable competitive advantage for the U.S.. They are particularly appropriate when the technologies address societal challenges and technical and scientific problems of national importance. We elaborate on these approaches in Chapter 4.

PCAST has not sought to define the specific technology areas that should be supported in this manner; this is better done through a process that we describe below. For the purposes of illustration, we briefly describe four examples of promising technologies that face potential market failure such as described above.

- **Nano-scale Carbon Materials:** Materials such as graphene, buckeyballs, and carbon nanotubes that have nano-scale crystalline structures could serve markets for data storage, energy, optoelectronics, avionics, defense and packaging. Potential products include highly attuned chemical and biological sensors, fuel cells, touch screens, lightweight body armor, and airframes. Their properties could also allow the materials to replace silicon for next-generation integrated circuits, and to be applied to uses not yet conceivable. Because these materials could serve a diverse range of industries including energy, information storage, automotive, aerospace and microelectronics, it is hard for individual firms—or even individual industries—to reap the benefits of high-risk investments to realize the full potential of the technologies.
- **Next-generation optoelectronics:** Technology that integrates electronics and photonics to convert light into electrons, and vice versa, currently enables many products and services in telecommunications, entertainment, e-commerce and medicine. The next generation[62] of the technology requires development and production of vastly more integrated, higher-performance, and lower cost devices and systems, which could also allow for the emergence of new microelectronics, order-of-magnitude improvements in data transfer rates within and between computers without increased cost, biosensors for home healthcare and personalized medicine, imaging and night-vision systems, and faster and more capable information synthesis and processing systems. The critical innovation needed in this field is the ability to integrate leading-edge photonic functionality into the same chips as transistor-based electronics. This will leverage the existing infrastructure for electronic silicon chip fabrication to rapidly advance the manufacturing base for new photonic systems. The benefits of developing this technology are spread across a wide range of industry sectors and products. Individual firms cannot justify the level of investment needed to fully develop the technology.
- **Flexible electronics:** The technology that allows electronic circuits to be printed on thin, flexible substrates that can be shaped without damage has the potential to improve a range of existing products including displays and photovoltaic panels and to form the basis of new products, such as bandages that sense the presence of infection and alert medical staff, foldable solar panels for earth and space applications, clothing that monitors and displays physiological signs, phased-array antennae for distributed mobile communications networks, and ultra-efficient lighting. The research and development needed to advance this technology is costly and complex, requiring facilities for prototyping and pilot-scale manufacture. Yet the benefits are broadly applicable across industries and cannot be fully captured.

62. The current state of the technology consists of silicon photonics that integrate photonic and electronic circuits, monolithically integrated into single substrates with bonded lasers fabricated from indium phosphide. The next generation of this technology will require substantial investment in developing processes that are 1) compatible with existing CMOS fabrication facilities, 2) stable and repeatable, and 3) accessible to the wider community and 4) offer best-in-class performance for both photonic and electronic devices.

- **Nanotechnology Enabled Medical Diagnostic Devices and Therapeutics:** Advances in nanomedicine have the potential to revolutionize the pharmaceutical industry, by dramatically improving prevention, diagnosis and treatment. Recent advances in nanotechnology have led to ultrasensitive assays for identifying and treating diseases at earlier stages than conventional diagnostic tools, new ways of delivering powerful therapeutics to the point of disease within the body without unintended side effects, and the development of entire new classes of pharmaceuticals based upon nanostructures for broad classes of disease such as cardiovascular disease and cancer. The ability to design products and manufacture using this technology requires new tools and procedures, scale-up plants, and a work force with a new set of skills. The technology has the potential to create new US-based industries, lower the cost of health-care, and positively impact human life. But, individual medical firms cannot rationally justify the optimal level of investment based on the return that they can achieve.

Opportunities: Supporting Shared Infrastructure

A second way that the Federal Government can promote advanced manufacturing in the U.S. is to improve access to infrastructure, especially for small and medium sized firms.

There are many tools and technologies that can improve the ability of existing firms to prototype rapidly and virtually, produce small batches, customize products to individual consumers and clients, reduce inventories, and expand the range of products that they can manufacture. Many firms, however, cannot gain access to such technologies. The minimum investments required are too large to be cost-effective for an individual firm, and there is often no effective way to buy shared services.

For example, powerful computational tools and resources for modeling and simulation could allow many U.S. manufacturing firms to improve their processes, design, and fabrication. They would benefit from readily accessible shared infrastructure, providing both equipment and expertise. Infrastructure currently provided at Federal laboratories, for example, for the fabrication of micro-electromechanical systems, has allowed for new products to be developed by U.S. companies. Similarly, measurement tools for nanomaterials would be enabling for many firms.

Opportunities: Rethinking the Manufacturing Process

A third way that the Federal Government can promote advanced manufacturing in the U.S. is by supporting broad efforts to dramatically rethink the manufacturing process.

We believe that emerging technologies—if accelerated, integrated, and synthesized—have the potential to change how we manufacture things ranging from vehicles to personal effects, from tools to proteins. Harnessed and driven appropriately, they have the potential to create a new manufacturing base that can move quickly, cost-effectively and seamlessly from bits to atoms and from parts to systems. The resulting manufacturing tools and resources may enable:

- development cycles at reduced risk, time and cost;
- adaptive design and development for diverse market segments; and
- orders of magnitude expansion of number and diversity in product designers.

Past efforts to accelerate product development cycles and reduce costs of transition to large scale manufacturing have often focused on rapid prototyping tools and techniques. While there have been important developments in these areas, rapid prototyping has not solved the fundamental challenges of manufacturing. Rather than making prototyping techniques faster, more functional, and closer to mass production, it may make more sense to work backward from manufacturing—by developing the tools and techniques that would enable large scale manufacturing equipment and materials to efficiently produce low volume lots—down to units of one. This would enable production of prototypes in exactly the same facility that will produce units in high volume. Prototyping new products in exactly the same high-volume manufacturing facility using the same materials and processes that will be used in the final product could revolutionize production speed and efficiency in the transitions between stages. It could eliminate the time, cost, and risk that arises from transitions between stages that include prototyping, early production runs, limited, and large-scale manufacturing. These transitions currently require extensive rework, and are the source of production delays, surprises, and cost overruns.

The power of this approach has been demonstrated historically in the semiconductor and information technology industries. In semiconductors, the work of Mead and Conway in the late '70s fundamentally transformed the design of very large-scale integrated (VLSI) systems. They developed an 'abstract' set of design rules that made it possible to decouple the design of systems from the specific fabrication technology used to produce them. As a result, design and simulation tools with higher level of abstractions became possible. These abstractions and tools involved a trade-off that required some loss of optimal performance in individual components. But, they allowed much greater ease and accuracy of the overall system design. These advantages led to system-level innovations that increased system performance, reduced time and cost of system design, and increased reliability and predictability of system performance. The tools and techniques led to a greater diversity and number—from hundreds to hundreds of thousands—of VLSI designers. These designers in turn contributed to a proliferation of new semiconductor products, dozens of multi-billion dollar companies and an entire new industry sector—fabless semiconductor companies.

Similar to the semiconductor sector, information technology moved from machine-level, assembly language programming in the 1960s to high-level languages that decoupled the programming from the specific microprocessor or machine that was being programmed. High-level languages involved a deliberate tradeoff of some loss of performance for ease of programming and portability of programs. As in semiconductors, the move to higher-level languages, higher levels of abstraction, also led to a greater diversity and number of programmers, which in turn led to an explosion of new programs, applications and the information technology industry.

Manufacturing sectors such as electromechanical systems and pharmaceuticals may involve greater levels of complexity and technical challenge than semiconductors or programming alone. Similar approaches, however, hold promise to bring comparable growth, jobs, and entrepreneurial innovation to key industries and U.S. manufacturing excellence. We see three areas for attention.

The first area is in design tools that dramatically improve the existing systems engineering, integration, and testing process for complex electromechanical, cyber-physical systems that represent the bulk of manufactured products today— from toasters to automobiles. These tools could aim to develop general methods for cyber-physical products far more complex and heterogeneous than those to which such methods are applied today. These capabilities would further enable designers to use common methods throughout the design process to optimize system performance, and to verify designs in silico. This could dramatically reduce the need for expensive build, test and design cycles.

The second area would develop manufacturing facilities similar to today's semiconductor foundries. The input would be verified system designs, specified and developed with the design tools above. The systems would be capable of rapid reconfiguration to accommodate a wide range of design variation. Such foundries would compress substantially the time required to go from design to product. This could advance manufacturing toward flexible, programmable, and potentially distributed production capabilities able to accommodate a diverse range of systems and system variants, rather than requiring separate facilities for single products.

The third area would support generating open-source collaboration environments for the creation of large, complex, cyber-physical systems by numerous affiliated or unaffiliated designers—with the goal of democratizing the design innovation process by engaging a vastly larger pool of talent than current industry models. The development of complex software systems, for example, has benefitted significantly from the ability to leverage crowd-sourced innovation in the form of open source code development.

CONCLUSION

Individual companies cannot justify the investment required to fully develop many important new technologies or to create the full infrastructure to support advanced manufacturing. Private investment must be complemented by public investment. Key opportunities to overcome market failures include investing in the advancement of new technologies with transformative potential, supporting shared infrastructure, and accelerating the manufacturing process through targeted support for new methods and approaches.

IV. Recommendations: Toward a Renaissance in Advanced Manufacturing

In a spirit consistent with America's past successes, we recommend the following strategy for promoting advanced manufacturing in the United States.

PRINCIPLES FOR PROMOTING ADVANCED MANUFACTURING IN THE UNITED STATES

(1) Invest to overcome market failures, to ensure new technologies are developed here and technology-based enterprises have the infrastructure to flourish here.

- **Support applied research programs in most promising new technologies**
- **Co-invest in public-private partnerships to facilitate development of broadly-applicable technologies with transformative potential**
- **Develop and disseminate design methodologies that dramatically decrease the time and lower the barrier for entrepreneurs to make products**
- **Invest in shared technology infrastructure that would help U.S. companies improve their manufacturing**

(2) Create a fertile environment for innovation here.

- **Encourage firms to locate R&D and manufacturing activities in the U.S. through tax and business policies**
- **Support a robust basic research enterprise**
- **Ensure a supply of skilled workers through policies that cultivate and attract high-skilled talent**

The recent passage of the America COMPETES Reauthorization Act of 2010 establishes a valuable framework for activities to support advanced manufacturing (see Appendix 1). The Act authorizes the Federal government to work with industry and national laboratories to identify regulatory and tax barriers to advanced manufacturing, identify challenges appropriately tackled by PPPs, and encourage the formation of PPPs. It authorizes an interagency committee under the NSTC to plan and coordinate federal activities on advanced manufacturing. It also directs NIST to study the barriers to small and medium sized firms' use of modeling and simulation tools and techniques, and requires the Department of Commerce to recommend actions to overcome any barriers that are identified. We urge funding be appropriated for these activities.

The President's FY2012 budget request and President's Strategy for American Innovation lay out specific actions to catalyze advanced manufacturing initiatives (see Appendix 2) that include modifications to the R&D tax credit, modest R&D funding for advanced manufacturing at various agencies, foundational support for public-private partnership programs at NIST, and investments in STEM education. We also urge appropriate funding for these activities.

Our goal here is to build upon this foundational work, including by identifying specific actions and the funding required.

Overcoming Market Failures: Advanced Manufacturing Initiative for America's Future

There are systematic market failures that (i) block or slow the development of important new technologies and methodologies and (ii) limit access by firms to technology infrastructure. The Federal Government has historically made visionary investments that have facilitated the birth of new technology-based industries and strengthened the development of existing industries. These investments have paid enormous financial and social returns to the Nation. It is essential that we renew this wise policy.

PCAST believes there are a number of Federal investments that could have large returns in propelling advanced manufacturing. These include co-investing in the advancement of new technologies that face market failure, support of shared infrastructure, and rethinking the manufacturing process through targeted support for new methods and approaches. Currently, key technological investments in this vein are being made by the Defense Advanced Research Projects Agency (DARPA), the National Institute of Standards and Technology (NIST) and the Department of Energy.

Rather than specifying precise areas for investment, however, PCAST favors the creation of a disciplined and transparent process to evaluate technology opportunities, define problems or cross-cutting challenges, and make investments. Investments should be made based on the merits of proposals from industry and academia, evaluated by the criteria discussed below.[63]

Toward this end, we recommend the creation of an **Advanced Manufacturing Initiative for America's Future (AMI)**. AMI should be a concerted, whole-of-government effort, spearheaded by the Department of Commerce, Department of Defense, and Department of Energy and coordinated by the Executive Office of the President (EOP), either through the Office of Science and Technology Policy, National Economic Council, or the office of the Assistant to the President for Manufacturing Policy. It is crucial that this whole-of-government effort be complemented by parallel initiatives in the industry and academia. AMI should develop mechanisms to involve these sectors and to draw on their expertise in identifying technological opportunities. An external advisory board that has access to advanced manufacturing expertise should help guide this work.

AMI should focus on two components: identifying opportunities and investing in opportunities. The first component requires no new appropriations and should be launched immediately. The second component could require new appropriations or reprioritization of existing funds.

Identifying Opportunities. The Coordinator of AMI should deliver a biennial report to the President identifying and analyzing the most promising technology areas related to advanced manufacturing where Federal investment is needed and justified. The types of investments to be considered should include:

63. We note that PCAST has not sought to evaluate how the overall funding portfolio might be rebalanced. Instead, we have identified gaps and needs that are not being met currently.

- Coordinated Federal support to academia and industry for applied research on new technologies and design methodologies with transforming potential,
- Public-private partnerships to advance such technologies through pre-competitive consortia that tackle major-cross-cutting challenges,[64]
- Development and dissemination of design methodologies that dramatically decrease the time and lower the barrier for entrepreneurs to make products,
- Shared facilities and technology infrastructure to help small and medium-sized firms improve their products to compete globally.

The report should also identify specific challenge areas for the Nation that merit focused attention. (Possible examples of challenge areas might include: highly flexible manufacturing for biopharmaceutical production; improving photovoltaic systems to become the cheapest source of power within the decade; or design, simulation, and production of electromechanical systems with the complexity of automobiles or infantry fighting vehicles.)

In addition, the report should study the availability of financing for these areas of technology, including comparison of access to low-cost financing in other nations and evaluation of options for providing revenue-neutral development investment opportunities. In addition, consideration should be given to addressing the challenges that surround manufacturing readiness and the scale-up of manufacturing processes.

Investing in Opportunities. We recommend that funding be appropriated to the Department of Commerce, the Department of Defense, and the Department of Energy (DOE) to allow NIST, DARPA and DOE to fund the most promising opportunities that will respond to cross-cutting challenges and problems defined by AMI, through programs at each agency.

At NIST, the AmTech program provides a model for how this can work by providing a vehicle for public-private partnerships, with mechanisms for cost-sharing by industry and states. Currently, AmTech is only a pilot program with a proposed budget of about $12 million. Germany's Fraunhofer Program offers a potential model for shared infrastructure facilities and resources.

We believe that the Federal investment level should initially be $500 million per year, to be allocated across the three agencies, rising to $1 billion over four years. Some of these funds may be drawn from existing programs as appropriate.

We note that the recent reauthorization of the America COMPETES Act provides for public-private partnerships in key advanced manufacturing technologies to be formed and funded by the Federal Government, but that the implementation of PPPs depends upon funds being allocated for this purpose. (We note that the Presidents FY2012 budget request proposes funds for this purpose).

The Federal investment should leverage substantial investment by industry—especially in the case of PPPs, where industry might perhaps cover half the cost. Such cost-sharing is an important indicator of industrial commitment and will help ensure that these investments pay off in terms of economic growth.

64. These might include specific technology areas such as the examples in Box 2, or the development of new production and measurement equipment.

We recognize that budgetary constraints will make new investments difficult in the coming years. However, we believe that the proposed program has the potential to pay large economic returns to the Nation relative to the funding required.

Criteria. Investments should be made where there is a compelling case. In the case of support for applied research in specific technologies or in new design and manufacturing methodologies, these areas should be justified by the potential for transformative impact.

In the case of public co-investment in PPPs, AMI should solicit specific proposals from consortia of private and public organizations. (Where necessary and appropriate, it should offer modest-sized planning grants to support the preparation of such proposals; we believe planning grants can be funded from existing funds.) Opportunities should be selected based on the merits of the proposals, and based on the below criteria:

- The technology area has a high potential payoff in employment and output.
- There is a prospect of sustainable competitive advantage for the U.S., including through first-mover advantage.
- Identifiable market failures impede adequate private investment.
- PPPs include industrial partners willing to co-invest with the government.
- PPPs include some industrial partners with sufficient size to invest at scale in the fruits of the pre-commercial research, as well small and start-up enterprises.
- Investments will help anchor subsequent manufacturing in the United States—for example, through shared labs, pilot plants, technology infrastructure and creation of clusters.
- Shared infrastructure will help existing firms and industries compete globally by increasing the quality and performance of their products

AMI should also establish metrics for determining effectiveness of these investments made by agency-specific programs, a function that could be coordinated through the NSTC subcommittee on advanced manufacturing.

RECOMMENDATION 1: LAUNCH ADVANCED MANUFACTURING INITIATIVE

The Federal Government should launch an Advanced Manufacturing Initiative for America's Future (AMI). AMI should be a concerted, whole-of-government effort, spearheaded by the Department of Commerce, Department of Defense, and Department of Energy and coordinated by the Executive Office of the President (EOP), either through the Office of Science and Technology Policy, National Economic Council, or the office of the Assistant to the President for Manufacturing Policy. The Secretaries of Commerce, Defense, and Energy should assign lead responsibility to an appropriate agency or agencies within the Department—such as National Institute of Standards and Technology (NIST) at Commerce, DARPA at Defense, and ARPA-E or EERE at Energy. It is crucial that this whole-of-government effort be complemented by parallel initiatives in the industry and academia. AMI should develop mechanisms to involve these sectors and to draw on their expertise in identifying technological opportunities. An external advisory board that has access to advanced manufacturing expertise should help guide this work.

The coordinating body of AMI should prepare a biennial report to the President on the most important needs for Federal investments to propel advanced manufacturing in the U.S., including (i) Coordinated Federal support to academia and industry for applied research on new technologies and design methodologies, (ii) Public-private partnerships (PPPs) to advance such technologies through pre-competitive consortia that tackle major-cross-cutting challenges, (iii) Development and dissemination of design methodologies that dramatically decrease the time and lower the barrier for entrepreneurs to make products, (iv) Shared facilities and infrastructure to help small and medium-sized firms improve their products to compete globally. The report should also identify the most pressing technological challenges that merit focused attention for these activities.

AMI should also report on the availability of financing for pilot plants and early-stage activities within these technology areas, and should include an analysis of comparable financing opportunities in other countries and options for providing revenue-neutral financing.

Funds to implement the programs recommended by AMI should be appropriated to the Departments of Commerce, Defense, and Energy to support the most promising opportunities. The funding level should be initially be $500 million per year to be allocated across the three agencies as appropriate, rising to $1 billion over four years. Some of these funds may be drawn from existing programs as appropriate.

Because advanced manufacturing has unique national security implications, and because DARPA has, within the DoD, a unique ability to connect to small, entrepreneurial companies, DARPA has a vital role in Recommendation 1's proposed initiative. More broadly within DoD, initiatives in manufacturing going beyond Recommendation 1 may be an important part of acquisition reform and the improvement of supply chain management. Such initiatives can help transition and mature early stage DoD research investments into technologies ready for scale up and deployment into national security systems in a more cost effective and timely fashion than available at present. AMI should engage experts from industry and academia in identifying technological opportunities, and work with an external advisory board that has access to advanced manufacturing expertise.

In implementing AMI, the Federal Government should also consider incentives and policy tools that will anchor advanced manufacturing activities to the United States.

BOX 2: EXAMPLES OF IMPORTANT TECHNOLOGY AREAS FOR ADVANCED MANUFACTURING

The following technologies represent potential areas that would align with the criteria PCAST has outlined for public-private investment to support advances in manufacturing:

Advanced robotics. Next-generation robots could be mobile and autonomous in their environment, with the ability to interact with their environment and achieve outcomes without programming of all procedures. They also have the potential to be safely operable around humans or in dangerous environments. Intelligent automation could build robots' capabilities to increase autonomy and flexibility to enable manufacturers to respond to needs and desires of customers very efficiently. Major advances could provide broad-based innovation benefiting multiple industries, such as that provided by computer-aided design and computer-aided manufacturing, total quality management, and just-in-time manufacturing. The private sector currently under-invests in robotics technology as the full benefits are dispersed across many firms and industries. Public-private investments to advance robotics technology could help US manufacturers compete by allowing quick, nimble improvements in product quality, productivity, time to market, and cost.

Nanoelectronics. Semiconductors have been one of the key enabling technologies of the information technology revolution. The technology has driven ongoing improvements in price and performance of computers, phones and other communications equipment. Experts believe that today's microprocessor technology (the silicon CMOS field effect transistor) will reach its limits in terms of performance around 2020. The most promising candidates for the next "logic device" are being identified collaboratively by experts in industry, academia, and government, through joint research initiative known as the Nanoelectronic Research Initiative (NRI). New research on fabrication techniques, materials, heat flow and power dissipation are necessary to achieve the next generation of technologies that will support a broad range of industries and applications. The benefits of investing substantially in such research are widespread but difficult for individual industries and firms to capture alone. Federal co-investment is important to ensuring the U.S. industries leads the next microprocessor technology, as it led the last.

Materials by Design. Materials that endure in extreme temperatures, lightweight composites and new electronic and functional materials have in the past enabled advances in transportation, electronics, and aerospace and have given U.S. companies a competitive edge. A new generation of materials is needed for a broad range of applications including energy storage, flexible electronics, and stronger, more versatile defense products. But new materials often take 10-15 years from the initial research stage to be integrated into applications, and there is a trend toward increasing speed of product design. U.S. companies require tools for rapid discovery, development, and use of advanced materials. Investments need to be made in developing broadly available tools. These include modeling and software tools, databases of design material properties, and tools for testing materials more rapidly.

Biomanufacturing. Researchers are developing new tools that could allow us to readily engineer biological systems, with widespread applications for energy, medicine, and electronics. Further development of these tools could dramatically reduce the time and cost of realizing biotechnology applications such as biosynthesis of pharmaceuticals, efficient conversion of sunlight and carbon dioxide into fuel, and assembly of inorganic materials into electronic devices or batteries. The development of enabling science and technologies is an important potential area for Federal co-investment.

Creating a Fertile Environment: Tax Policy, Research Enterprise and Skilled Workers

In addition to this strategic initiative to promote advanced manufacturing, the Nation must cultivate the conditions to attract and retain advanced manufacturing activities in the United States. This involves several facets of innovation policy:

Corporate tax policy. The Federal Government has an essential role in shaping the environment in which U.S. manufacturers compete, through its tax policies. We urge the Federal Government adopt two policies outlined in the President's plan, which are widely supported by the scientific and business communities.

RECOMMENDATION 2: IMPROVE TAX POLICY

The Federal Government should:

- **Reform corporate income taxes, to bring the marginal tax rate in line with other OECD countries, as advocated by President Obama in his 2011 State of the Union address. This will create stronger incentives to locate manufacturing plants in the U.S. and help eliminate the disincentive to repatriate profits, and instead, draw companies to use them to employ U.S. workers.**
- **Extend the R&D tax credit permanently and increase the rate to 17%, as advocated in the Presidents' Strategy for American Innovation and FY2012 budget request. Knowing that the credit will persist will encourage firms to lengthen their time horizon for R&D investments. The rules governing the tax credit should also be examined to make clear that R&D on manufacturing processes qualifies for the credit.**

Robust research enterprise. Basic and applied research is the critical foundation for innovation. As stated in the first *Gathering Storm* report from the U.S. National Academy of Sciences, "A balanced research portfolio in all fields of science and engineering research is critical to U.S. prosperity."[65] President Obama has recognized this need for a strong research base to support advanced manufacturing in the administration's framework to revitalize manufacturing.

The Federal Government has traditionally supported both basic and applied scientific and engineering research, including much of the research performed by universities. Yet, the Federal Government's funding of R&D as a fraction of GDP has declined by 60% over the past 40 years.[66] Corporate R&D spending has risen rapidly, but it is directed largely toward development. The Federal Government largely retains responsibility for the funding of basic research, performed largely at the Nation's research universities and institutes.

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65. National Academy of Sciences, National Academy of Engineering, Institute of Medicine, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*. Washington, DC: National Academies Press. 2005.

66. Federal R&D was equivalent to 1.92% of GDP in 1964, and 0.76% of GDP in 2004. http://www.nsf.gov/statistics/nsf10314/pdf/tab13.pdf.

Supply of skilled workers. In the long term, the strength of our innovation system depends on the skill of our workforce. Manufacturers increasingly need employees who bring substantial technological abilities. As the original *Gathering Storm* report stated, "The competitiveness of U.S. knowledge industries will be purchased largely in the K-12 classroom."

Importantly, we need a workforce that includes not only scientists and engineers with advanced degrees, but also factory-floor engineers able to oversee and improve complex manufacturing processes and workers able to use sophisticated tools and machinery in factories. Manufacturing firms frequently cite the inability to find an adequate supply of factory engineers and workers as a barrier to locating manufacturing in the U.S.

Numerous studies have described the challenges in K-12 science, technology, engineering, and mathematics (STEM) education in the U.S., which include a shortage of highly qualified and effective teachers, the lack of dynamic, adaptive instructional materials, low achievement on international standardized tests and national assessments, and low student interest in STEM-related careers.[67] PCAST has explored this topic and delivered to the President a recent report on K-12 STEM education.[68] In this report, PCAST recommends specific actions to improve the effectiveness of Federal investments in K-12 education. In 2011, PCAST plans to deliver a follow-up report on undergraduate STEM education.

In addition, the United States must continue to draw the best talent from abroad. In the near term, steps must be taken to expand the number of available H1-B visas for those with advanced education in science and engineering. Due to the stringent constraints on visas, tens of thousands of highly qualified graduates of U.S. colleges and universities return to their home countries each year. U.S. companies have tremendous need for such workers. Moreover, foreign-born scientists and technologists greatly contribute to the U.S. economy by starting enterprise here. Roughly one-third of start-up firms in Silicon Valley are started by foreigners.

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67. For example, in the Programme for International Student Assessment (PISA), which measures students' ability to apply what they have learned in science and technology and has been designed to assess the kinds of skills needed in today's workplace, U.S. 15-year-olds scored below most other nations tested in 2006. The U.S. standing dropped from 2000 to 2006 in both mathematics and science. Also, the World Economic Forum ranks the United States 48th in quality of mathematics and science education.55 World Economic Forum, The Global Competitiveness Report 2009-2010, Available at: http://www.weforum.org/pdf/GCR09/Report/Countries/United%20States.pdf.

68. President's Council of Advisers on Science and Technology. *Prepare and Inspire: K-12 Education in Science, Technology, Engineering and Mathematics for America's Future.* http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-stemed-report.pdf

RECOMMENDATION 3: SUPPORT RESEARCH, EDUCATION, & TRAINING

To ensure the health of the research enterprise that underpins innovation and national security and to ensure that that the Nation has the highly skilled workforce needed to attract and maintain advanced manufacturing in the U.S, the Federal Government should:

- **Fulfill the President's plan to double the research budgets of three key science agencies over the next ten years: the National Science Foundation, the Department of Energy's Office of Science, and the National Institutes of Standards and Technology.[69] Ensure that other research agencies have appropriate research budget levels.**
- **Use Federal policy and leadership to fulfill the President's goal that public and private investment R&D reach 3% of GDP.**
- **Strengthen science, technology, engineering and mathematics (STEM) education, as described in the recommendations in PCAST's recent report.**
- **Expand the number of high-skilled foreign workers that may be employed by U.S. companies. This can be done by such policies as allowing foreign students that receive a graduate degree in STEM from a U.S. university to receive a green card, allowing each employment-based visa to automatically cover a worker and his or her spouse and children[70], and increasing the number of H1B visas.**

69. www.whitehouse.gov/innovation/strategy
70. Currently, more than half of the 140,000 employment-based visas are used to admit spouse and children.

Appendix A: Advanced Manufacturing Provisions in America Competes Act

The America COMPETES Act, passed by Congress in December 2010 and signed into law by President Obama in January 2011, contains provisions that support advanced manufacturing.

- It authorizes increased funding for basic research funding through the National Science Foundation (NSF), the Department of Energy's Office of Science, and the National Institute for Standards and Technology (NIST) in the Department of Commerce (DOC).
- It authorizes policies supporting science, technology, engineering and mathematics (STEM) education, as well as policies to strengthen the nation's innovation and competitiveness.
- It directs the Department of Commerce to analyze: the innovation capacity and economic competitiveness of the United States; the performance of the U.S. relative to other nations; the business, tax, and regulatory climate for innovation; trade and export policies; workforce issues; the effectiveness of Federal, state and regional policies; and barriers to U.S. competitiveness in emerging technology areas. In consultation with an Innovation Advisory Board of industry and other experts, the Department will develop a 10-year innovation and competitiveness strategy for the United States to address the issues in the study.
- It directs the creation of an interagency committee on technology under the National Science and Technology Council (NSTC) with responsibility to plan and coordinate Federal programs and activities on advanced manufacturing, including R&D programs of federal agencies, translation and commercialization of federally-funded technology into manufacturing, and the formation of private-public partnerships. It requires that the committee set and make strategic plans to achieve short and long-term objectives for R&D, worker training, and assistance to small and medium-sized manufacturers.
- It directs the Manufacturing Extension Partnership, a program of NIST, to improve training at community colleges of workers to serve the needs of small and medium-sized manufacturing businesses, and to evaluate the barriers faced by small-sized manufacturers and assist in responding to these challenges via the regional manufacturing extension centers. The MEP would also be expanded to support construction and green energy industries.
- It establishes a dedicated program in NSF to fund fundamental research at higher-education institutions that will lead to "transformative advances" in manufacturing technologies, processes, and enterprises. Proposed research areas include: nanomanufacturing; machines and equipment for manufacturing and construction including robotics and automation; manufacturing enterprise systems; advanced sensing and control techniques; materials processing; and information technology for manufacturing including modeling and simulation capabilities.
- It directs NSF to support higher education institutions for STEM internship programs for undergraduate students to work in industry. The NSF would also fund programs to strengthen and

expand technical and scientific education and training in advanced manufacturing, including through NSF's Advanced Technological Education program.

- It directs DOC to create a program of Federal loan guarantees for small and medium—sized manufacturers pursuing the use or production of innovative technologies for manufacturing.
- It directs DOC to study barriers to use of high-end computing simulation and modeling by small- and medium-sized U.S. manufacturers, including access to facilities and resources, availability of software and technologies, and access to expertise, and tools to manage costs. The study would yield recommendations for responding to these challenges to increase use of high-end computing modeling and simulation. In addition, Federal agencies could carry out demonstration and pilot programs as part of the study.

Appendix B: President Obama's Strategy for American Innovation and the FY 2012 Budget Request: Implications for Advanced Manufacturing

The President's Strategy for American Innovation, updated in early 2011, and the President's 2012 budget propose several initiatives and programs to support advanced manufacturing. These programs provide a strong foundation for a broader strategy on Advanced Manufacturing, as described in our recommendations. The provisions include the following:

- Increased R&D budget for advanced manufacturing technologies: Funding for the NSF, NIST, DOE and DARPA intended to support innovation to reinvigorate existing manufacturing industries and support the development of new industries. Specifically, the President proposes that:
  - NSF increase by $87 million its basic and applied research funding for promising areas of advanced manufacturing technologies, including materials design, nano-manufacturing, next-generation robotics, and cyber-physical systems such as smart buildings.
  - DARPA invest $1 billion in advanced manufacturing over the five years to transform and dramatically decrease the time of design and production for manufacturing defense systems, vehicles, and other products.
  - NIST laboratories be allocated $760 million to support development of measurements and technological advances in areas including nano-manufacturing, network security, and bio-manufacturing, with increases of $120 million directly for advanced manufacturing.
  - DOE be allocated $500 million to support energy-related advanced manufacturing technologies, such as flexible electronics and ultra-light, ultra durable automotive materials.
- Creation of a public-private partnership program to support platform technologies that will support innovation in manufacturing. The budget calls for $12 million in 2012 to fund these partnerships via the Advanced Manufacturing Technology Consortia (AMTech) program, and for $75 million to be dedicated to PPPs via the Technology Innovation Program (TIP), in particular for technologies that could improve manufacturing processes.
- Incentives for clean energy manufacturing innovation and investment, including the expansion of the Clean Energy Manufacturing Tax Credit from $2.3 billion to $5 billion, with the goal of incentivizing $11.7 billion in private sector investment in clean energy manufacturing projects, firms, and jobs. The current tax credit program has been oversubscribed, and has had proven successful in leveraging private sector investment and creating jobs.
- Investments to support infrastructure for innovation in manufacturing, including establishing a new $3 billion Wireless Innovation Fund to support applied research and development of

new communications technologies. The President has also proposed the creation of a National Infrastructure Bank to support high priority projects, sustained investments in high-speed rail, and air traffic control.

- Strengthening of the R&D tax credit. The President has proposed raising the credit from 14% to 17%, simplifying it for use by a broader swath of businesses, and making the credit permanent.
- Investments in improving STEM Education, including the preparation of 100,000 new STEM teachers over the next decade with strong content knowledge and teaching skills and the creation of ARPA-ED, a mission driven agency for education technology to improve learning and aid teaching.

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