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INNOVATION, LEADERSHIP, AND NATIONAL SECURITY

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and James A. Wrightson, Jr.

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EXECUTIVE SUMMARY

Innovation will be a crucial requirement for US leadership and national security in the twenty-first century. The United States faces an era of global competition across all elements of national power. In the economic arena, American domination has necessarily been comparatively receding as the world continues to develop. Militarily, challenges have expanded geographically and qualitatively as multi-polarity and diffusion of power increases the number of capable state and nonstate actors. Diplomacy has become more complex as information capabilities are available throughout the world, populaces are more engaged, and there are strong ideological challenges to the Western, liberal rules-based model. The United States is still the most powerful nation, but maintaining successful leadership and strong national security will require the United States to build on and enhance its existing strengths. A crucial element of that requirement will be the capacity to innovate regularly and effectively. Innovation will be a prerequisite to leadership across all elements of national power.

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This report proposes that both the US government and the American private sector take significant steps to encourage innovation beyond what the United States, already an innovative society, has successfully accomplished. The key elements will be enhanced development of the "cluster model" for innovation, which engages the public, private, and nonprofit sectors jointly; greater government focus on innovation; increased support for innovation by corporations; expanding the spectrum of entrepreneurs; and maintaining the diversity of ideas and approaches necessary for innovation while expanding the synergies between and among the multiple elements of the innovation landscape, including increasing the permeability between the national security agencies and the private sector. More specifically, the recommendations are:

A. Enhanced deployment of the cluster model

1) Expand nonmanufacturing clusters, which would bring together public, private, and nonprofit entities, to areas not now covered or which would benefit from greater focus, including quantum computing, artificial intelligence, human augmentation, nanotechnology, synthetic biology, genomics, Alzheimer's research, and cyber security. The President's Council of Advisors for Science and Technology (PCAST) should undertake a review [with input from the private sector, nonprofits such as the American Academy for the Advancement of Science, as well as government organization such as the Defense Advanced Research Projects (DARPA) and the National Institutes of Health (NIH)] and make recommendations for such expansion to the President and the Congress. This could be an important task for the new administration after the 2016 election.

2) Expand the manufacturer "cluster" model (currently being implemented by the National Network for Manufacturing Innovation (NNMI) and which does bring together public, private, and nonprofit entities) to additional manufacturing areas and to include the establishment of research laboratories, technology testbeds, "skunk works," and prototyping and production capabilities in selected key areas recommended by PCAST (with input from the private sector, as well as government organizations such as the DARPA and NIH). The expansion of the NNMI could also be an important action by the new administration.

B. Greater government focus on innovation

3) Increase federal funding for research and development to at least one percent of GDP with approximately one-half to go to basic and advanced research.

4) Expand access to international research and development by organizing coordination with key entities outside the United States including through the establishment of collocated research centers in select countries at universities and similar entities.

5) Expand government efforts into key focused arenas with projects that nurture innovation, such as quantum computing, artificial intelligence, human augmentation, nanotechnology, synthetic biology, genomics, Alzheimer's research, and cyber security as recommended by the governmental advanced research projects agencies and NIH (with input from the private sector that could be organized through PCAST). The use of Grand Challenges in these areas should be expanded. The Office of Science and Technology Policy could coordinate this for a new administration.

C. Increased support for innovation by corporations

6) Authorize creation of tax-advantaged subsidiaries and investments, including tax-free technology bonds, focused on innovation in critical areas as recommended by PCAST (with input from the private sector, as well as government organization such as the DARPA and NIH).

7) Authorize "innovation assessments" by regulators to include assessment of technology-regulation linkages, such as regulation-driven innovation and effects on innovation by major federal actions significantly affecting markets. Knowledgeable organizations such as the National Science Foundation (NSF) could be tasked to provide expert input to regulators who would utilize the input as part of their discretionary decisions.

D. Encourage Greater Development of Entrepreneurs

8) Encourage increased "philanthropic entrepreneurs" efforts into innovation, especially through social and cultural incentives, building on the models of the Giving Pledge, the Science Philanthropy Alliance, the use of prizes, and similar efforts.

9) Encourage talent growth through the expansion of clusters as an attractive environment for elite researchers and the development of technical training through community college and online courses for the creation of the necessary production and related skills as well as expanded efforts on diversity.

E. Expand synergy between and among the key elements of the innovation landscape but encourage diverse approaches so as to maximize the prospect of innovation

10) Expand the permeability between national security agencies and the private sector by revising the federal acquisition approach in order to support key innovative defense and national security projects including the Department of Defense's (DOD's) "Third Offset Strategy." Utilize multiple approaches to find and acquire innovative technologies, consider the potential of acquisition policy to deal with the "Valley of Death" faced by new enterprises, and accept certain risks, such as nonuniformity in acquisition and greater control of intellectual property by private entities.

INTRODUCTION

Innovation will be a crucial requirement for US leadership and national security in the twenty-first century. The United States faces an era of global competition across all elements of national power. In the economic arena, American domination has necessarily been comparatively receding as the world continues to develop. Militarily, challenges have expanded geographically and qualitatively as multi-polarity and diffusion of power increases the number of capable state and nonstate actors. Diplomacy has become more complex as information capabilities are available throughout the world, populaces are more engaged, and there are strong ideological challenges to the Western, liberal rules-based model. The United States is still the most powerful nation, but maintaining successful leadership and strong national security will require the United States to build on and enhance its existing strengths. A crucial element of that requirement will be the capacity to innovate regularly and effectively. Innovation will be a prerequisite to leadership across all elements of national power.

This report proposes that both the US government and the American private sector take significant steps to encourage innovation beyond what the United States, already an innovative society, has successfully accomplished. The key elements will be enhanced development of the "cluster model" for innovation, which engages the public, private, and nonprofit sectors jointly; greater government focus on innovation; increased support for innovation by corporations; expanding the spectrum of entrepreneurs; and maintaining the diversity of ideas and approaches necessary for innovation while expanding the synergies between and among the multiple elements of the innovation landscape, including increasing the permeability between the national security agencies and the private sector.

I. THE INNOVATION IMPERATIVE—LEADERSHIP AND NATIONAL SECURITY

> *"[R]esearch has become central; it also becomes more formalized, complex, and costly," President Dwight D. Eisenhower, Military-Industrial Complex Speech, 1961*

> *"Whether it's improving our health or harnessing clean energy, protecting our security or succeeding in the global economy, our future depends on reaffirming America's role as the world's engine of scientific discovery and technological innovation. " Remarks by President Barack Obama on the "Educate to Innovate" Campaign and Science Teaching and Mentoring Awards, January 6, 2010*

The United States has long been the world's most innovative society, and that innovation has been a key element undergirding America's international leadership and strength. The national security strategy states that "Scientific discovery and technological innovation empower American leadership with a competitive edge that secures our military advantage, propels our economy, and improves the human condition."[1] This requirement for innovation has become increasingly critical as America's overwhelming dominance in other arenas—a key factor in the twentieth century—has been comparatively reduced.

- Economically: While the United States remains the world's largest economy, there are expectations that it will be overtaken in gross size by China.[2] Per capita income in the United States is below multiple countries[3] while median real income has actually fallen since 1999.[4]

- Militarily: While United States forces have unparalleled capabilities, the challenges posed by Iraq, Afghanistan, ISIS, the world-wide demands of counterterrorism, Russian actions in Ukraine and elsewhere, and the confrontations in the East and South China Seas all demonstrate the multiple and diverse demands that the military faces. Without innovation in defense capabilities, the United States will face technological parity, losing the advantage it has maintained for over half a century.

- Ideologically: The United States faces what might be called the "geopolitics of resentment" with China, Russia, and a portion of the Muslim world rejecting the international liberal order to a significant degree. China, for example, has banned the teaching of Western ideas in its schools.[5] Russia has engaged in active repression of free speech and has regularly criticized the United States and the liberal Western model.[6] ISIS has rejected all international norms and engaged in brutal and destructive behavior.[7]

- In the informational arena, China, Russia, and ISIS (as well as other significant actors) both constrain free speech and make good use of the capabilities created by the Internet. China's "Great Firewall" effectively limits information available to the Chinese populace.[8] Russia has, among other things, just established new digital media requirements, further restricting speech while at the same time establishing

1 "National Security Strategy," February 2015, p. 16, https://www.whitehouse.gov/sites/default/files/docs/2015_national_security_strategy.pdf.

2 According to some analysis, that has already occurred if purchasing power parity is used as the measure and if one believes China's statistics. See Ben Carter, "Is China's economy really the largest in the world?" BBC News Magazine, December 14, 2014, http://www.bbc.com/news/magazine-30483762.

3 World Bank, GDP per capita, 2016, http://data.worldbank.org/indicator/NY.GDP.PCAP.CD

4 Neil Irwin, "Why Americans Still Think the Economy Is Terrible," *New York Times,* September 16, 2015, http://www.nytimes.com/2015/09/17/upshot/why-americans-still-think-the-economy-is-terrible.html?smprod=nytcore-iphone&smid=nytcore-iphone-share&_r=0; United States, Census, Table H-6, http://www.census.gov/hhes/www/income/data/historical/household/; see Keith Miller and David Madland, "What the New Census Data Show About the Continuing Struggles of the Middle Class," September 16, 2014, Center for American Progress, https://www.americanprogress.org/issues/economy/news/2014/09/16/97203/what-the-new-census-data-show-about-the-continuing-struggles-of-the-middle-class/.

5 Jamil Anderlini, "Western values' forbidden in Chinese universities," *Financial Times,* January 30, 2015, http://www.ft.com/cms/s/0/95f3f866-a87e-11e4-bd17-00144feab7de.html#axzz3rU1ipRUI; "Chinese Universities Told to Ban 'Western Textbooks'," Radio Free Asia, January 30, 2015, http://www.rfa.org/english/news/china/universities-ban-western-textbooks-01302015132241.html.

6 Neil MacFarquhar, "Putin Accuses U.S. of Backing 'Neo-Fascists' and 'Islamic Radicals'," *New York Times,* October 24, 2014; See Andrei Kolesnikov, "Russian Ideology after Crimea," Carnegie Moscow, September 22, 2015, http://carnegie.ru/2015/09/22/russian-ideology-after-crimea/ihzq.

7 The attacks in Brussels, Paris, Beirut and the bombing of the Russian passenger plane being only the most recent.

8 See, for example, James Griffiths, "Great Firewall rising: How China wages its war on the Internet," CNN (Updated 9:29 PM ET, Sun October 25, 2015), http://www.cnn.com/2015/10/25/asia/china-war-internet-great-firewall/.

effective propaganda outlets such as the RT network now available in multiple countries.[9] ISIS runs social media both for recruiting and propaganda purposes.[10]

Even though the United States is no longer dominant in the way it has been, it still is the world's leader and possesses many advantages. The capacity to innovate has been a chief element and is likely to be fundamental in determining our international competitive advantage in the future. Looking back at the past thirty years, for example, there have been major innovations driven by United States companies across the economy. Some innovations, such as global positioning systems, have become so well-entrenched that it is easy to forget they did not exist commercially only a few decades ago, but not only have they become integrated into everyday life, but they are also helping to generate new innovations such as self-driving cars. Others like online shopping and prompt merchandise delivery, exemplified by companies like Amazon are now regular features of American life. Likewise, smart mobile phones not only allow us to carry powerful computers in our pockets but they have the prospect of affecting national and urban demographics as many workers no longer need to be tied to an office. Of course, each of the foregoing is simply part of the information and Internet revolution, led by United States companies, including Microsoft, Apple, IBM, Google, Cisco, Verizon, and AT&T (as well as the revolution in the social media exemplified by Facebook and Twitter). But innovation has hardly been limited to information systems. Other sectors are dramatically changing, and the innovation leaders in these will establish competitive advantage while shaping the future world. These include:

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- energy—the shale revolution, which has changed the world energy situation as well as its geopolitics;
- robotics—drones, manufacturing, and other capabilities that are still developing;
- 3-D printing—utilized by both small and large companies and helping to reset United States manufacturing;
- genomics and other biologic advances—with the prospect of new health cures, including the recent announcement of potential new antibiotic capacities;
- nanotechnology—the ability to create new properties in materials that can lead to major new structural methods or devices based on new magnetic, electronic, or optical characteristics;
- bio/information technology interfaces—which are leading to extraordinary capabilities for those with artificial limbs, paralysis, and blindness, and which may be available to enhance the capacities of the entire population in the future; and
- quantum computing—the capability to solve problems of such complexity that it will revolutionize analytical, predictive, and design aspects of business and government.

As the foregoing suggests, even if the United States has lost dominance in some arenas, it still is the lead actor in innovation.[11] The key issue for American leadership and strength, however, is whether that will hold in the future. Both officials and commentators have raised the alarm. The Deputy Secretary of Defense is on record that in the United States, "technological superiority is slipping . . . So it's all about innovation, it's all

9 See, for example, Neil MacFarquhar, "Russia Quietly Tightens Reins on Web with 'Bloggers Law'," *New York Times*, May 6, 2014, http://www.nytimes.com/2014/05/07/world/europe/russia-quietly-tightens-reins-on-web-with-bloggers-law.html.

10 See, for example, J.M. Berger and Jonathon Morgan, "The ISIS Twitter Census: Defining and describing the population of ISIS supporters on Twitter," Brookings Institution, March 2015, http://www.brookings.edu/research/papers/2015/03/isis-twitter-census-berger-morgan.

11 There are some who think there are a few countries ahead of the United States in innovation. The Global Competitiveness Report ranks the United States fifth behind Switzerland, Japan, Finland, and Germany for "innovation and sophistication" factors. See "The Global Competitiveness Report 2014-2015," p. 14, http://www.weforum.org/reports/global-competitiveness-report-2014-2015. Our view is that, based on actual innovation, the United States has been far and away the most innovative country for a very long time.

about staying ahead of potential adversaries."[12] The American Energy Innovation Council has highlighted its recommendation that "The Scale of the Challenges Facing the United States Demands a Step-Change in Energy Innovation Investment."[13] Other industries face similar challenges, as, for example, in pharmaceuticals, where one involved participant stated, "It has become very difficult to find new drug classes to fight infections . . . There haven't been enough incentives for the industry to take on 10 or 15 years of research."[14] Indeed, one knowledgeable commentator has gone so far as to assert that over the "past 30 years," the United States has come to be in an "entrepreneurial slump" thereby "risk[ing] losing its status as a global leader in innovation."[15] While the conclusion regarding the past thirty years does not seem justified in light of the innovative efforts noted above, the question of the future is more open.

It is easy enough to see how, in a globalized, multipolar world, there could be challenges. As the Defense Science Board has stated:

> "While the U.S. is still the world's technology leader, the gap with other nations is closing . . . . The projected global technology landscape indicates that the U.S. should not plan to rely on unquestioned technical leadership in all fields."[16]

An important consideration is that, as the Defense Science Board has pointed out, "An increasing fraction of the world's basic research is being conducted outside the United States."[17] While there are positive aspects to that, such as the work done by the Chinese scientist regarding malaria and traditional Chinese medicine that won a Nobel Prize,[18] the potential risks from that change are also clear enough.[19] For example, innovation could occur in countries like China and Russia that might not be accessible to the United States. Each has national capabilities that, for example, China has used to become a very significant factor in world trade or as the Soviet Union used in developing military technologies during the Cold War. The Secretary of Defense has stated, "Indeed, technologies once long possessed by only the most formidable militaries have now gotten into the hands of previously less-capable forces, and even non-state actors. Nations like Russia and China are modernizing their militaries to try to close the gap and erode our superiority in every domain – air, land, sea, space, and cyberspace."[20] This is not to suggest that these countries are at a stage now to become formidable competitors in innovation. Rather, it is to point out that the dynamic could change in a relatively shorter time frame, just as China's economy and Russia's military have developed significantly over the past ten years. The report by the American Energy Innovation Council, noted above, underscores the point:

> "Events today threaten America's future competitiveness. While the United States maintains a significant lead in energy technology patenting overall, companies in other countries are jumping into the fray. China, for example, is increasingly rivaling the United States in public RD&D investments, particularly in energy. Germany is dedicating increasing funds to Fraunhofer Institutes, 70

12 Robert Work, "Deputy Secretary of Defense Speech at the Army War College Strategy Conference," April 8, 2015, http://www.defense.gov/Speeches/Speech.aspx?SpeechID=1930.

13 American Energy Innovation Council, *Restoring American Energy Innovation Leadership: Report Card, Challenges, and Opportunities*, February 2015, p. 13; see also Eduardo Porter, "Innovation Sputters in Battle Against Climate Change," *New York Times*, July 15, 2015, http://mobile.nytimes.com/2015/07/22/business/energy-environment/innovation-to-stanch-climate-change-sputters.html.

14 Eduardo Porter, "A Dearth in Innovation for Key Drugs," *New York Times*, July 22, 2014, http://mobile.nytimes.com/2014/07/23/business/a-dearth-of-investment-in-much-needed-drugs.html. The challenges do go beyond the United States. For example, The International Energy Administration has stated, "for the first time since the IEA started monitoring clean energy progress, not one of the technology fields tracked is meeting its objectives. As a result, our ability to deliver a future in which temperatures rise modestly is at risk of being jeopardised, and the future that we are heading towards will be far more difficult unless we can take action now to radically change the global energy system." International Energy Administration, *Tracking Clean Energy Progress*, 2015, p. 4.

15 Robert Litan, "Start-Up Slowdown," *Foreign Affairs,* January/February 2015, pp. 47, 49.

16 Defense Science Board, "Technology and Innovation Enablers for Superiority in 2030," October 2013, p.vii, http://www.acq.osd.mil/dsb/reports2010s.htm.

17 Defense Science Board Task Force, Report on Basic Research, Office of the Secretary of Defense, January 2012, p. x, http://www.acq.osd.mil/dsb/reports/BasicResearch.pdf. Indeed, United States companies such as General Electric although doing research inside the US, also are building R&D laboratories outside the US.

18 Ian Johnson, "Nobel Renews Debate on Chinese Medicine*, New York Times*, October 10, 2015, http://www.nytimes.com/2015/10/11/world/asia/nobel-renews-debate-on-chinese-medicine.html?_r=0.

19 Of course, not all technological developments outside the United States are negative. An example of worldwide development that appears to have significant positive upsides is the block chain. See, for example, Kariappa Bheemaiah, "Block Chain 2.0: The Renaissance of Money," Wired.com, http://www.wired.com/insights/2015/01/block-chain-2-0/.

20 Ashton Carter, Secretary of Defense, Remarks at DARPA's "Wait, What?" Future Technology Conference September 9, 2015\, http://www.defense.gov/News/Speeches/Speech-View/Article/616661/remarks-at-darpas-wait-what-future-technology-forum.

different research institutes, each organized around a strategic area and designed to produce practical technologies, especially energy technologies. The United States must proactively prepare for a more competitive economic future and scale up innovation investments as other countries increase their own innovation investments."[21]

In sum, in a globalized world, the United States needs to focus on enhancing its innovative capacities in order to maintain its international leadership and national security capacities.

II. THE NATURE AND SOURCES OF INNOVATION

Innovation arises in multiple fashions. The past 150 years have seen the creation of very large and complex systems such as aircraft and the development of very small systems, such as semiconductor circuitry. Innovative physical processes have been developed such as the chemical processes that stimulated the steel industry and production line processes that enabled affordable cars. Service process innovation, such as the container revolution and "just-in-time" inventories revolutionized logistics and the goods transportation industry. Information innovation processes, such as the Internet, have entirely changed our ways of interacting.

As these examples suggest, innovation can be defined as the "application of new ideas to the products, processes, or other aspects of the activities of a firm that lead to increased 'value.' This 'value' is defined in a broad way to include higher value added for the firm and also benefits to consumers or other firms."[22] While that definition is focused on the private sector, the government can, of course, generate innovation also, and the impact may, at least initially, be focused on governmental operations, such as in the military arena. But whether private sector or governmental or some combination, innovation occurs only when it actually impacts a segment of the economy. It is more than just discovery or invention:

"Another feature . . . of innovation is that the product or process must be introduced into the market place so that consumers or other firms can benefit. This distinguishes an innovation from an invention or discovery. An invention or discovery enhances the stock of knowledge, but it does not instantaneously arrive in the market place as a full-fledged novel product or process. Innovation occurs at the point of bringing to the commercial market new products and processes arising from applications of both existing and new knowledge."[23]

As the foregoing suggests, time is a factor for successful innovation, and innovations rarely arise as quickly as they may seem to. To be sure, sometimes the value is quickly understood, and the innovation becomes successful in a short time. However, in most cases it takes a somewhat longer time for the public to adopt it fully (though time for adoption in the information arena seems to have shortened as compared to earlier innovations).[24] Often the initial innovation must be refined through additional secondary innovation for general use by the public. For example, air travel became popular only multiple decades after Wilber and Orville Wright flew at Kitty Hawk. The Internet took off during the 1990s, but its innovation origins began in the 1960s.

Innovation does not arrive without hard work, and it is probably useful to recognize that most innovations do not occur as a result of a single individual acting entirely by himself. In his book, *The Myths of Innovation*, Scott Berkun states,

"Despite the myths, innovations rarely involve someone working alone, and never in history has an innovation been made without reusing ideas from the past. . . . [O]ur newest ideas have historic roots; the term *network* is *500* years old, webs were around before the human race, and the algorithmic DNA is more elegant and powerful than any programming language.

21 American Energy Innovation Council, op. cit., p. 14.

22 Christine Greenhalgh and Mark Rogers, Innovation, Intellectual Property and Economic Growth (Princeton, NJ: Princeton University Press, 2010), p. 4.

23 Greenhalgh and Rogers, op. cit., p. 5.; See Sarah Webster, "Inside America's Bold Plan to Revive Manufacturing, Manufacturing engineering," May 14, 2015, http://www.sme.org/MEMagazine/Article.aspx?id=8589934630. ("Converting a proven scientific idea into a commercial manufacturing technology is very, very expensive, partly because it can take a lot of time, involving many rounds of trial and error, as well as intersecting sciences. Development of these technologies can be slow, incremental and span decades.").

24 Rita McGrath, "The Pace of Technology Adoption Is Speeding Up," *Harvard Business Review* (November 25, 2013), https://hbr.org/2013/11/the-pace-of-technology-adoption-is-speeding-up/.

Wise innovators—driven by passion more than ego—initiate partnerships, collaborations, and humble studies of the past, raising their odds against the timeless challenges of innovation."[25]

This is not to say that entrepreneurs are not important—some type of entrepreneurial-like action is critical in the process of converting a concept or an invention to an innovation; rather it is only to point out that even the entrepreneur does not act alone. Moreover, as the foregoing suggests, there are multiple different models for innovation. At least four models of promoting and funding transformative innovation have appeared over the last 150 years. These can be described as the entrepreneurial model, the corporate research laboratory model, the government project model, and the hybrid government research-private development model.

There are multiple different models for innovation: . . . the entrepreneurial model, the corporate research laboratory model, the government project model, and the hybrid government research-private development model.

—As suggested above, perhaps the most well-known model has been the entrepreneurial model. Key visionary inventors have been responsible for many of the innovations of the last 150 years. These visionaries have often persevered against the status-quo, and developed not only inventions but also businesses. Of course, this has been quite risky, and there have been a lot of small business failures. Those that have been successful have found funding and promoted a vision of the future that caught the attention of both the investing and consuming sectors of society.

A recent but very important variant on this model is the philanthropic entrepreneur. Over the past twenty years or so, possessors of significant private fortunes have dedicated very substantial funding toward innovation efforts. Some are technologically focused such as Paul Allen's funding of artificial intelligence research.[26] Others include process oriented actions (sometimes combined with research) such as the Gates Foundation's efforts to combat certain diseases in Africa.[27] Some are expanding new product capabilities such as the space efforts by Elon Musk's Space X and Jeff Bezos' Blue Origin. Many successful entrepreneurs are funding new R&D that supports innovation. As a New York Times analysis found:

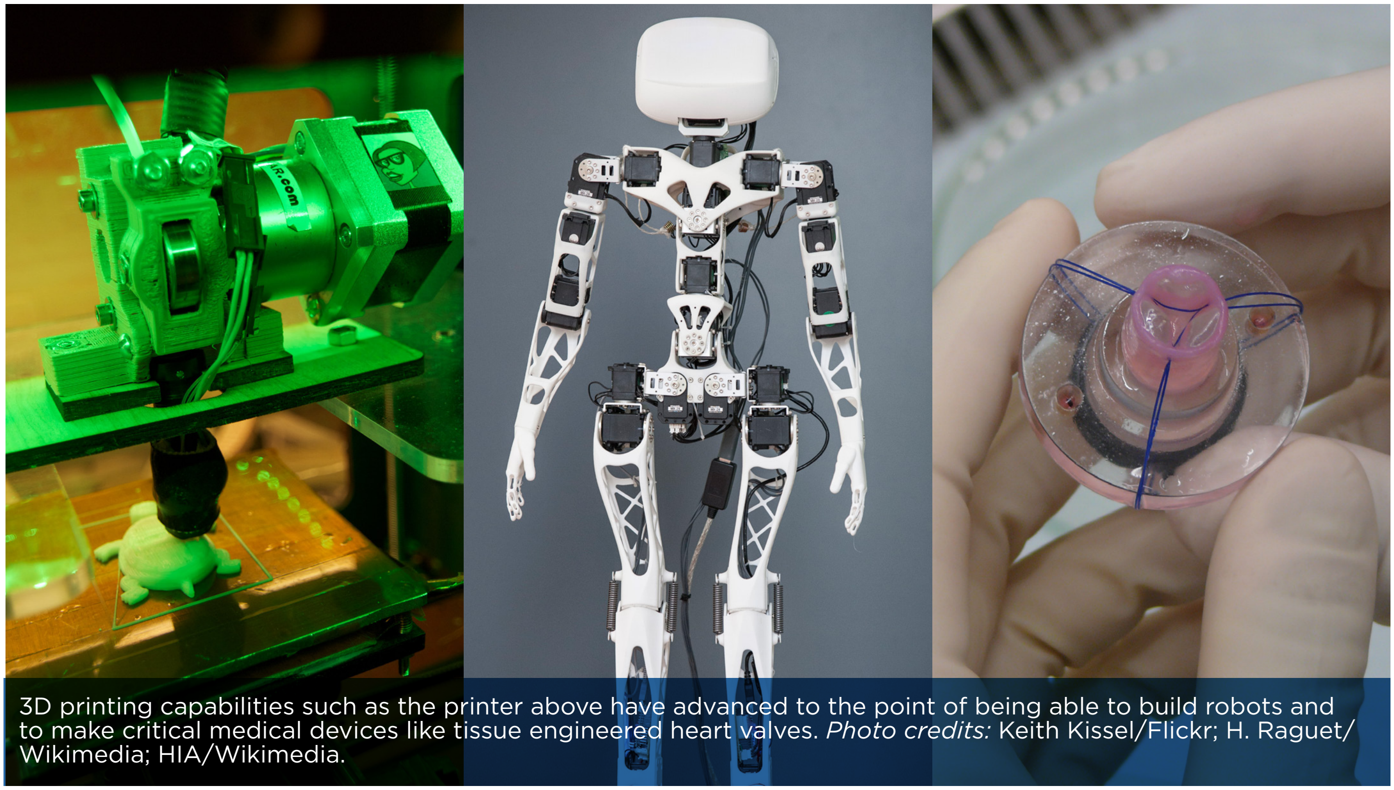
"The philanthropists' projects are as diverse as the careers that built their fortunes. [For example,] George P. Mitchell, considered the father of the drilling process for oil and gas known as fracking, has given about $360 million to fields like particle physics, sustainable development and astronomy—including $35 million for the Giant Magellan Telescope, now being built by a private consortium for installation atop a mountain in Chile. . . . Eli Broad, who earned his money in housing and insurance, donated $700 million for a venture between Harvard and the Massachusetts Institute of Technology to explore the genetic basis of disease. Gordon Moore of Intel has spent $850 million on research in physics, biology, the environment and astronomy. The investor Ronald O. Perelman, among his other donations, gave more than $30 million to study women's cancers—money that led to Herceptin, a breakthrough drug for certain kinds of breast cancer. Nathan P. Myhrvold, a former chief technology officer at Microsoft, has spent heavily on uncovering fossil remains of Tyrannosaurus rex, and Ray Dalio, founder of Bridgewater Associates, a hedge fund, has lent his mega-yacht to hunts for the elusive giant squid."[28]

25 Scott Berkun. The Myths of Innovation (Sebastopol, CA: O'Reilly Media, Inc., 2010), 81.

26 Ariana Eunjung Cha, "Thought process: Building an artificial brain," *Washington Post,* September 30, 2015, http://www.washingtonpost.com/sf/national/2015/09/30/brain/.

27 Bill and Melinda Gates Foundation, Press Release, Gates Foundation Commits More than $500 Million to Tackle The Burden of Infectious Disease in Developing Countries, http://www.gatesfoundation.org/Media-Center/Press-Releases/2014/11/ASTMH-Address; Bill and Melinda Gates Foundation, Africa Health Fund, http://www.gatesfoundation.org/How-We-Work/Quick-Links/Program-Related-Investments/Africa-Health-Fund.

28 William Broad, "Billionaires with Big Ideas Are Privatizing American Science," *New York Times*, March 15, 2014, http://mobile.nytimes.com/2014/03/16/science/billionaires-with-big-ideas-are-privatizing-american-science.html.



3D printing capabilities such as the printer above have advanced to the point of being able to build robots and to make critical medical devices like tissue engineered heart valves. *Photo credits:* Keith Kissel/Flickr; H. Raguet/ Wikimedia; HIA/Wikimedia.

—A second innovation model is the corporate research laboratory model, which has been used by large corporations in growth businesses to develop new major products. General Electric was well known for its successful introduction of a series of major innovations. IBM, Xerox PARC, and ATT's Bell Labs are three other examples that produced some of the major technologies of the twentieth century. A few examples of the innovations that had their bases in these laboratories include the transatlantic telephone cable, the UNIX operating system, light emitting diodes, laser printing, and the Ethernet. A current example of innovative corporate research is the rapid development of IBM's Watson's ability to analyze unstructured data, now increasingly involved in medical diagnosis with future potential yet to be determined.[29]

The corporate research laboratory model that brought some of the greatest information technologies had a dominant effect in the twentieth century, but many corporate laboratories were sharply reduced in the 1990s. As investment timelines became shorter, and large corporations focused on near-term business, the corporate R&D also looked more toward less risky (and thus less innovative) activities. The trend might be somewhat reversing as new large corporations such as Google continue to fund visionary new product efforts.

—A third very important innovation mechanism has been the government project model, a combination of government funding and project direction. Government activity during the Cold War period is particularly notable, including the development of many different technologies such as semiconductors, lasers, and information networks, all of which started as defense efforts but evolved into major new industries. Government innovation projects have also benefitted from the organizational model, exemplified by the Defense Advanced Research Projects Agency, which seeks to achieve highly significant breakthroughs. Other areas of government, such as the intelligence community and the Energy Department have adopted this model.

Government funding and projects can sometimes provide more comprehensive and quicker innovative results by making the technology more widely available than, under certain circumstances, does the private sector as was the case with the human genome where in the

> "competition to decode the human genetic blueprint . . . the public Human Genome

29 IBM.com, Offerings: IBM Watson for Oncology, http://www.ibm.com/smarterplanet/us/en/ibmwatson/watson-oncology.html.

> Project . . . put every gene it sequenced straight into the public domain . . . [while] the private company Celera Genomics . . . patented the genes it sequenced first for up to two years. [The result] . . was substantially less subsequent research and product development based on the genes sequenced by Celera than on genes immediately put up for free public use. Had governments also patented their discoveries, gene science could have been slowed substantially."[30]

—A fourth model is the hybrid government research-private development model, a form of public-private collaboration. Shale oil and gas extraction, the Internet, and computers are all good examples where the public sector financed early research but the private sector carried through the work, so that invention led to actual innovation in the broad marketplace.

Whatever the model, it is also important to highlight, as Berkun does, that innovation almost always builds on prior innovation and requires effective collaboration. Tim Harford, the Financial Times well-known "Undercover Economist," has written, "Simpler products require simpler networks of collaboration, and can be produced almost anywhere. More complex products require elaborate networks of teamwork, and only a few places manage the trick."[31]

A great deal of invention that can become innovation occurs at the intersection of disciplines. Thus, initial invention or potential innovative concept development is likely enhanced by the interaction of diverse backgrounds and disciplines.

As the foregoing implies, many innovations establish a foundation of knowledge for further innovative breakthroughs. Thus, after a baseline has been developed, a further innovation in a given field might require a broader set of knowledge and more funding to achieve than the initial introduction in that sector. For example, carbon nanotube electronics arguably might have been innovated by an entrepreneur with a small chemistry laboratory if that entrepreneur would only have had to produce simple circuitry. However, in today's world, a successful nanotube electronic circuit has to compete with the highly developed state of silicon technology; consequently, only a major, well-funded research effort could succeed. In point of fact, only recently, IBM scientists apparently have found a way to make transistors from parallel rows of carbon nanotubes, an example of what a well-funded research effort with multiple capabilities can accomplish.[32] In short, the hurdle for innovation can get higher over time and often requires more resources and attention. Efforts at innovation need to take this challenge into account.

As Harford suggests, a great deal of invention that can become innovation occurs at the intersection of disciplines. Thus, initial invention or potential innovative concept development is likely enhanced by the interaction of diverse backgrounds and disciplines. Semiconductors blended chemistry and quantum mechanics with electrical engineering circuitry. The microwave oven applied radiation generators to the chemistry of thermal heat in tissues. A great deal of information technology has involved applying mathematical concepts to physical interactions of people and machines. Modern innovation is often generated by diverse groups sharing perspectives.

Innovation is thus multi-dimensional, has a time factor, and involves more than just insight and discovery. One commentator put it this way:

> "Thus we can see that innovation occurs at the kernel of a complex process, preceded by inventions and succeeded by the widespread adoption of the new genre of products by customers, or the adoption of best-practice processes in the majority of firms. We call this final stage *diffusion*, and it is clear that the

30 Eduardo Porter, "Government R&D, Private Profits and the American Taxpayer," *New York Times*, May 26, 2015, http://www.nytimes.com/2015/05/27/business/giving-taxpayers-a-cut-when-government-rd-pays-off-for-industry.html?_r=0.

31 Tim Harford, "Teamwork Gives Us Added Personbyte," Timharford.com, June 23, 2015, http://timharford.com/2015/06/teamwork-gives-us-added-personbyte/.

32 John Markoff, "IBM Scientists Find New Way to Shrink Transistors," *New York Times*, October 1, 2015, http://www.nytimes.com/2015/10/02/science/ibm-scientists-find-new-way-to-shrink-transistors.html?_r=0.

> benefits of innovation to the economy and its citizens are not fully realized until this has taken place."[33]

Although the process of innovation may appear sequential with technology breakthrough preceding diffusion, it is often far more interactive. Technological R&D would have difficulty getting high funding, unless there was a vision of a new market for it. But, of course, there could not be such a vision unless R&D helped point the way, though it is fair to say that sometimes serendipity plays a role also. In short, there is a complex interaction of R&D, market opportunity, and human element that interacts in innovation efforts.

Even among innovations, there are important degrees of difference. All innovations can be important, but some innovations alter the course of society and some do not. Home computers and Internet services are recent examples of innovations that have transformed our world. Older examples were air transportation connecting places, photography enabling rapid imaging of events, and steel processing enabling new construction. In the national security arena, the machine gun, the tank, stealth aircraft, and precision-guided munitions are all examples of transformative innovation.

The common feature of transformative innovation is that it changes a fundamental societal process, in addition to creating a product or service. Of course, innovations often begin in niche markets. The home computer market started as a niche for sophisticated users and gamers. The semiconductor industry got its initial start through defense products. The Internet initially connected research laboratories. However, transformative innovation generally involves new market demands, market expansions, and subsequent derivative innovation. In contrast, nontransformative innovation usually undertakes replacement of an existing product or service. Both forms of innovation are valuable, but transformative innovation can highly affect economic production and societal processes. Moreover, in so doing, it enhances the international competitiveness of the nation.

33 Greenhalgh and Rogers, *Innovation, Intellectual Property and Economic Growth*, op. cit., pp. 5-6.

III. THE ROLE OF FINANCE

Innovation requires finance. Broadly speaking, such finance comes from six sources: internal to companies; banks and similar lending institutions; private finance, such as venture capital, angel investors and private equity; stock and bond markets; government; and philanthropy and other nonprofit entities including universities. Each of these sources raises different considerations, including challenges, for innovation, and there is often a contest—and even a contradiction—between the challenges of finance and the value of innovation.

The challenges are straightforward and well-known. Innovation entails risk. The longer the time from R&D to market, the higher the risk. Thus, negative incentives exist whenever the innovative R&D is treated as an ordinary investment. This happens both internally to companies and with traditional sources of funding, such as banks. Private finance, government funding and philanthropic sources have different criteria and often are very important for this reason.

While, as noted, corporate innovation is highly important because of the ability of corporations to get new products into the marketplace, nonetheless, at the corporate level, "For more than a decade, growth in corporate profits has not been matched by growth in corporate investment."[34]

Generally, those funds have gone to stockholder return rather than to investment in innovation. Thus an "increasing amount of companies spen[d] a large percentage of their sales on buying back their stock and boost[ing] the value of stock options, closely linked to executive pay. . . . rather than in increasing their commitment to renewed innovation."[35]

Of course, increasing shareholder return is certainly not entirely irrational behavior on the part of corporate managers. The issue is the short-term

34 Neera Tanden and Blair Effron, "How To Foster Long-Term Innovation Investment," Center for American Progress, June 30, 2015, p. 2, https://www.americanprogress.org/issues/economy/report/2015/06/30/116294/how-to-foster-long-term-innovation-investment/. The article cites Carter C. Price, "What's the link between corporate profits, investments, and economic growth?" Washington Center for Equitable Growth, November 25, 2014, http://equitablegrowth.org/news/whats-link-corporateprofits.

35 Mariana Mazzucato, "Financing innovation: creative destruction v. creative creation," Industrial and Corporate Change, vol. 22, no. 4, p. 855-856, 2013, http://icc.oxfordjournals.org/content/22/4/851.abstract.

versus long-term point of view. Often, long-term investment does not fare as well in the market. As one analysis stated, "Indeed, precisely because innovation is a complex process frequently ending in failure, the stock market often penalizes firms after they announce the start of a challenging R&D project."[36]

The problem is compounded by the way banks, Wall Street investors, and other lending entities consider long-term projects. Often, it appears that "traditional profit maximizing banks fear the kind of fundamental uncertainty underlying innovation."[37] That is understandable as "[c]ompanies that spend more on R&D, for example, will inevitably have higher risk, as . . . innovation is so deeply uncertain—most attempts at innovation fail."[38]

The results of these disincentives can be consequential. As one analysis has pointed out,

> "Throughout the economy, this behavior could lead to lower growth if patient, longer term investments—positioned to generate more innovation and GDP growth—are not highlighted as a priority. . . . To be sure, many companies make long-term investments despite these obstacles. But it is not clear that forcing them to swim upstream against significant economic disincentives produces the best outcome."[39]

Despite these challenges, however, the empirical record demonstrates financing that supports innovation has grown over the past fifty years. In part, this has been a function of federal government funding. As the Congressional Budget Office has found:

> "Federal outlays for R&D more than doubled between 1962 and 2013 in real terms, driven mostly by an increase in spending for R&D related to defense during the defense buildup of the early 1980s and by an increase in spending for health research from 1998 to 2004. In 1962, federal outlays for R&D totaled about $59 billion (in 2013 dollars). By 2013, federal agencies were spending $132 billion for R&D . . . averaging a 1.6 percent real annual rate of growth between 1962 and 2013."[40]

There is no inevitability to such growth. The same Congressional Budget Office (CBO) study stated: "However, growth has been intermittent. For example, since 2009, real federal R&D spending has declined by about 10 percent."[41]

Moreover, when the question "how much is enough" is considered, it is useful to note that "When measured against the growth of gross domestic product, federal spending for R&D has generally declined since the 1960s (with the notable exceptions of the two periods discussed above)."[42]

However, the federal government is not the whole story: "Although federal R&D spending has been declining as a share of the economy overall, R&D expenditures from all sources reached 2.8 percent of GDP over the past several years, a level that had not been reached since the early 1960s."[43] The reason for this increase is that the private sector has had increasingly greater importance in terms of overall expenditures. The CBO study found:

> "Looking at the different stages of R&D and sources of spending, expenditures by private industry across all stages have grown in the past 50 years. The largest single shift was the increase in industrial development expenditures—up by 150 percent relative to the size of the economy—that almost completely offset the decrease in federal expenditures for development (which were mainly for activities related to defense and space exploration)."[44]

The importance of the nonfederal sectors is underscored by other trends:

> "Federal agencies also decreased their expenditures on applied research as a share of GDP by 45 percent, and an increase in spending by industry offset part of that decline. Federal agencies did increase their expenditures on basic research slightly relative to the size of

36 Mazzucato, op. cit., p. 854; Similarly, see Eduardo Porter, "American Innovation Lies on Weak Foundation," *New York Times*, May 19, 2015, http://www.nytimes.com/2015/05/20/business/economy/american-innovation-rests-on-weak-foundation.html?_r=0. "[T]he stock market places a lower valuation on original research than it did three decades ago. Corporate executives, their compensation tied overwhelmingly to short-term gains in the market value of their companies, may be responding accordingly."

37 Mazzucato, op. cit., p. 852,

38 Mazzucato, op. cit., p. 858.

39 Tanden and Effron, "How To Foster Long-Term Innovation Investment," op. cit., p. 2.

40 Congressional Budget Office (CBO), Federal Policies and Innovation (November 2014), p. 10, https://www.cbo.gov/sites/default/files/113th-congress-2013-2014/reports/49487-Innovation.pdf.

41 Ibid.

42 Ibid.

43 Ibid.

44 Ibid.

the economy, at the same time that other nonindustrial institutions such as universities, nonprofits, and state and local governments increased their expenditure share by almost twice as much."[45]

Some corporations do "swim upstream" and achieve significant results. While, as noted above, returning funds to shareholders is rational, the decision to spend for innovation can be even more sensible as the return from innovation is well-established even in the face of the risks:

"A recent study assessing growth among the 500 largest companies in the world found that investors realize outsized rewards when their companies invest aggressively in R&D and lose value when R&D spending is low. The fastest growing quartile of companies has increased in value by an average of 251 percent since 2012, versus an average of 69 percent for the next quartile. This significant increase in value was supported by substantially higher investment in R&D by companies in the top quartile compared with their peers."[46]

Ironically, long-term growth, which is critical for a corporation's success, requires innovation, but analysis is usually short-term and operationally based. This is significant, in part, because it can be modeled and measured. The exception is the analysis of growth stocks which are either small companies or companies with a history of innovative growth that analysts project into the future.

The increase in private sector funding does not offset the importance of public expenditure for innovation. As has been stated:

"Research is an obvious key to long-term productivity—one in which the public and private sectors both play crucial, complementary roles in ensuring that long-term gains are incentivized through smart policy choices. Public support for basic research is the only way to ensure certain kinds of foundational research can happen because there are limits to what markets can incentivize. For example, it is hard to make an investment case for publishing a new discovery about the laws of physics."[47]

The key would appear to be balance and the right type of incentives. As the same analysis further states,

"However, the vast majority of applied research and innovation comes from the private sector, where good public policy means a regulatory system that creates an environment that rewards private R&D when it is oriented toward long-term development and widespread adoption of the best innovative discoveries."[48]

IV. THE PROJECT, PARTNERSHIP, AND REGULATORY ROLES OF THE GOVERNMENT

Government has played multiple critical roles for innovation in the United States. In addition to finance, discussed above, the three most obvious are project direction, regulation, and, more recently, "cluster creation," including the development of public-private-nonprofit partnerships.

A. Project Direction

In the project arena, government policy plays two overlapping roles: focusing research and development toward an objective, and generating public-private interface for innovation related to that objective. In terms of the former, among many other examples, it was government research and development that laid the foundation for the computer, the Internet, and the shale revolution. Sometimes this is military led; in addition to the well-known DARPA lead on the Internet and the government's development of early computers, GPS and drones were each first military programs but now are universal (GPS) or developing quickly (drones and other robotics). Sometimes the funding can come through other agencies, such as the National Aeronautics and Space Administration (NASA) or the Small Business Administration. A recent Congressional Budget Office (CBO) study noted: "Economic studies have shown that federal support for R&D—particularly early-stage research—has long been very important in promoting innovation."[49]

45 CBO, op. cit., pp. 10-11.

46 Tanden and Effron, "How To Foster Long-Term Innovation Investment," op. cit., p. 8; The analysis cites Matthew A. Winkler, "Big Ideas, Big Spending, Big Payoff," Bloomberg, May 19, 2015, http://www.bloombergviewcom/articles/2015-05-19/big-ideas-big-spending-big-payoff.

47 Tanden and Effron, "How To Foster Long-Term Innovation Investment," op. cit., p. 3.

48 Tanden and Effron, "How To Foster Long-Term Innovation Investment," op. cit., pp. 3-4.

49 Congressional Budget Office, Federal Policies and Innovation, op. cit., p. 1.

Mariana Mazzucato has extensively discussed the role of the government in her "The Innovative State" article and previously in her book, *The Entrepreneurial State*. Mazzucato found, "In fact, in countries that owe their growth to innovation, the state has historically served not as a meddler in the private sector but as a key partner of it—and often a more daring one, willing to take the risks that businesses won't. Across the entire innovation chain, from basic research to commercialization, governments have stepped up with needed investment that the private sector has been too scared to provide. This spending has proved transformative, creating entirely new markets and sectors, including the Internet, nanotechnology, biotechnology, and clean energy."[50]

Two good examples are shale and pharmaceuticals, as Mazzucato has set forth:

> "In 1976, the Morgantown Energy Research Center and the Bureau of Mines launched the Eastern Gas Shales Project, which demonstrated how natural gas could be recovered from shale formations. That same year, the federal government opened the Gas Research Institute, which was funded through a tax on natural gas production and spent billions of dollars on research into shale gas. And the Sandia National Laboratories, part of the U.S. Department of Energy, developed the 3-D geologic mapping technology used for fracking operations.
>
> Likewise . . . many of the most promising new drugs trace their origins to research done by the taxpayer-funded National Institutes of Health, which has an annual budget of some $30 billion. Private pharmaceutical companies, meanwhile, tend to focus more on the D than the R part of R & D, plus slight variations of existing drugs and marketing."[51]

This is not just an academic's conclusion. The American Energy Innovation Council, consisting of the former heads of companies like General Electric, DuPont, Microsoft, and Lockheed Martin, has similarly stated:

> "U.S. companies are driving an energy boom today—in tight oil and shale gas production, renewable energy, efficiency, and much else—largely because they have significantly benefited from federally funded technology innovation, research and development over the last four decades. These investments, together with critical private-sector innovations and commercialization, have created dozens of technologies vital to America's economic growth, competiveness, and environment, such as unconventional gas extraction, advanced seismology, efficient clean engines, high-capacity batteries, natural gas turbines, and photovoltaic solar technology, among others."[52]

In each of these projects, the US focused both funding and attention on a problem that needed to be solved, or a system/process that needed to be created. In many cases, the government took one more very important step; it promised a market, often an initial niche market, for the results of the project. This created the economic incentive that stimulated private investment of time, talent, and money toward innovation.

Even though focusing attention on a problem is highly stimulating for innovation, the creation of an initial market is often more critical. Without it, some great ideas cannot overcome the market inertia that accompanies already established norms. Some of the best examples of this come from DOD, as in the case of early semiconductor and integrated circuitry that transformed electronics by replacing vacuum tubes, and ultimately led to computers. DOD offered a ready market in aircraft and space systems. One might wonder whether the forecasted transformation of current silicon electronics to carbon-based electronics will require a similar stimulation of a niche government market to emerge.

B. Cluster Creation—Public-Private-Nonprofit Partnerships

As discussed above, innovation is most often the result when there have been years of collaborative R&D efforts on key technology areas. Successful efforts in the past have built on having the best minds concentrate on a specific technology, and then involve a handful of extraordinary scientists and inventors to achieve significant advances. This is the heart of the cluster model of innovation—focusing the nation's intellectual talent of an emerging technology area as a collaborative endeavor, while still maintaining the diverse

50 Marianna Mazzucato, "The Innovative State,*" Foreign Affairs,* January/February 2015, p. 61, https://www.foreignaffairs.com/articles/americas/2014-12-15/innovative-state.

51 Mazzucato, op. cit., pp 63-64.

52 American Energy Innovation Council, Restoring American Energy Innovation Leadership, February 2015, Foreword, p. 1, http://americanenergyinnovation.org/restoring-american-energy-innovation-leadership/.

freedom of direction for each of the individual researchers and technologists.

The creation of clusters has been a role played by the federal government, which has expanded the capacity and effectiveness of public, private, and nonprofit entities to work together. One of the earliest examples was the development of cooperative research and development agreements under the Bayh-Dole Act of 1980, which have been extensively used to further research and development.[53] More recently, the government's public–private strategy is set forth in the federal government's "A Strategy for American Innovation."[54] The particulars include the National Science Foundation's Engineering Research Centers, the Department of Energy's Energy Innovation Hubs and Frontier Research Centers, and the National Network for Manufacturing Innovation. Each has a clear focus on the value of a public-private-nonprofit interface:

—Engineering Research Centers:

> "Each ERC is established as a three-way partnership involving academe, industry, and NSF (in some cases with the participation of state, local, and/or other Federal government agencies). In FY 2012, total annual funding from all sources provided directly to each Center ranged from $3.5 to $10.0 million, with NSF's contribution ranging from $2.7 million (for centers in their phase-down period prior to graduation from NSF support) to $3.25 to $4.2 million per year for ongoing centers. . . . NSF funds each ERC for up to 10 years. Since 1985, a total of 61 ERCs and 3 Earthquake ERCs have been formed across the United States, with 20 ERCs currently in operation."[55]

—Energy Innovation Hubs:

> "Modeled after the strong scientific management characteristics of the Manhattan Project and AT&T Bell Laboratories, the Energy Department's Energy Innovation Hubs are integrated research centers that combine basic and applied research with engineering to accelerate scientific discovery that addresses critical energy issues. The Hubs were first established in 2010 with the creation of the Consortium for Advanced Simulation of Light Water Reactors, which focuses on improving nuclear reactors through computer-based modeling. In total, there are currently four Hubs that work on everything from advance research to produce fuels directly from sunlight (the Joint Center for Artificial Photosynthesis) to improving battery technology for transportation and the grid (the Joint Center for Energy Storage Research) to developing solutions for rare earth elements and other materials critical to a growing number of clean energy technologies (the Critical Materials Institute)."[56]

—Energy Frontier Research Centers:

> "The Office of Basic Energy Sciences in the U.S. Department of Energy's Office of Science established the Energy Frontier Research Center (EFRC) program, to accelerate such transformative discovery, combining the talents and creativity of our national scientific workforce with a powerful new generation of tools for penetrating, understanding, and manipulating matter on the atomic and molecular scales. In 2009 five-year awards were made to 46 EFRCs, including 16 that were fully funded by the American Recovery and Reinvestment Act (ARRA). An open recompetition of the program in 2014 resulted in four-year awards to 32 centers, 22 of which are renewals of existing EFRCs and 10 of which are new EFRCs. These integrated, multi-investigator Centers involve partnerships among universities, national laboratories, nonprofit organizations, and for-profit firms that will conduct fundamental research focusing on one or more "grand challenges" and use-inspired "basic research needs" identified in major strategic planning efforts by the scientific community."[57]

—National Network for Manufacturing Innovation: The NNMI is designed as a collaboration among private industry, nonprofits including universities, and the federal government.

> "The institutes and the entire network will be industry-led. They will be designed and

53 See text of the Bayh-Dole Act, Cornell University Law School, https://www.law.cornell.edu/uscode/text/35/200; "What is a CRADA," Federal Laboratory Consortium, http://www.federallabs.org/home/faqs/.

54 A Strategy for American Innovation, National Economic Council and Office of Science and Technology Policy, October 2015, https://www.whitehouse.gov/sites/default/files/strategy_for_american_innovation_october_2015.pdf.

55 National Science Foundation, Engineering Research Centers, ERC Overview Fact Sheet 2012, http://erc-assoc.org/content/erc-program.

56 Energy.gov, "Hubs," http://www.energy.gov/science-innovation/innovation/hubs.

57 US Department of Energy, Office of Science, "Energy Frontier Research Centers (EFRCs)," November 24, 2015, http://science.energy.gov/bes/efrc/.

implemented in partnership with industry (companies large and small, established and start-up), academia, non-profit organizations, and states, and startup federal funding with the aim of investing in and accelerating the development of cutting-edge manufacturing technologies with industrially relevant applications."[58]

"At the federal level, the NNMI program is managed by the interagency Advanced Manufacturing National Program Office (AMNPO). Participating agencies include the Department of Defense, Department of Energy, Department of Commerce's National Institute of Standard and Technology (NIST), NASA, the National Science Foundation, Department of Education, and other agencies."[59]

The plan is to establish forty-five institutes focusing on different aspects of advanced manufacturing. The particular focus of the NNMI is Manufacturing Readiness Levels four to seven, which "are when a proven idea is further developed and scaled for a manufacturing environment through what is known as 'applied research.'" By contrast, "Levels 8 and beyond are when a technology is ready for prime time and produced in a production environment for sale to customers, who then use the technology to build products."[60]

At this writing, there are seven institutes, covering additive manufacturing; digital manufacturing and design; lightweight metal manufacturing; wide-bandgap semiconductor manufacturing; advanced composites manufacturing; integrated photonics manufacturing; and flexible hybrid electronics manufacturing. The first NNMI, known as America Makes—3D additive manufacturing, has pioneered the way forward by establishing public-private partnership relationships in all its research endeavors. These seven institutes fill a particularly important role in future innovation. By developing new manufacturing processes in key areas, product innovations are made easier to develop; they do not have to simultaneously invent the device and the basic technology that creates it. Barriers to market are reduced for both entrepreneurs and companies.

58 Manufacturing.gov, "How NNMI Works," http://manufacturing.gov/how-nnmi-works.html.

59 Ibid.

60 Sarah Webster, Inside America's Bold Plan to Revive Manufacturing, Manufacturing Engineering Magazine, May 14, 2015, p.10, http://www.sme.org/MEMagazine/Article.aspx?id=8589934630\.

C. Regulation

There is a substantial body of analysis on the relationships between regulation and innovation, and as an Organization for Economic Co-operation and Development (OECD) study stated, "Government regulations can have both positive and negative effects on the innovation process."[61] This is because, as another analysis set forth:

"[T]here are two competing ways in which government regulation impacts innovation. First, regulation places a *compliance burden* on firms, which can cause them to divert time and money from innovative activities to compliance efforts. For example, financial reporting regulation may cause a firm to redirect resources from its R&D division to its internal auditing division. Counter to this, and second, firms may be unable to achieve compliance with existing products and processes and thus, assuming the firms do not shut down, regulation may spur either compliance innovation or circumventive innovation."[62]

Given these conflicting impulses, the overall impact of government regulation on innovation is often unclear:

"Regulation that does not require innovation for compliance will generally stifle innovation, although it may spur circumventive innovation if the firm or industry can find a path to escape the regulatory constraints. . . . This is evident in many cases where social regulation causes social innovation to increase but causes market innovation to decrease. Hence, the net impact of this sort of regulation on innovation is unclear; there is no way to know whether the resulting social innovation is more valuable to society than the market innovation that was forgone. Nor is it clear whether regulation that requires compliance innovation will enhance firm or industry competitiveness."[63]

61 Organisation for Economic Co-Operation and Development, "Regulatory Reform and Innovation," p. 3.

62 Luke A. Stewart, "The Impact of Regulation on Innovation in the United States: A Cross-Industry Literature Review," Information Technology & Innovation Foundation, June 2010, p. 2, http://www.itif.org/publications/2011/11/14/impact-regulation-innovation-united-states-cross-industry-literature-review.

63 Stewart, op. cit., p. 23. There is also a distinction between economic and social regulation: "*Economic regulation* sets market conditions. Some examples of economic regulation are price controls, market entry conditions, production obligations, the regulation of contract terms, and most regulations governing the finance industry. . . . *Social regulation* is the

Regulation may also be viewed in a different perspective that is unique to innovation. Since transformative innovation changes societal processes, regulation can play an important role. It can either inhibit or accelerate the innovation's societal change. In cases where regulations tend to perpetuate existing structures, these regulations may unintentionally inhibit a transformative innovation and any attendant beneficial effects. A current example might be innovation in personalized medicine; to address how new medical innovations might be better regulated and not unduly burdened, the FDA has created projects to explore improving its regulatory systems. On the other hand, certain types of regulation can also propel innovation forward when it eases commercial risk barriers. We would not have as robust a commercial satellite launch capability today if it was not for regulation that reduced the risk of a catastrophic failure.

However, there appear to be better and worse ways to undertake regulation. Three factors that bear most importantly on the impact of regulation are the stringency of the regulation, its flexibility, and the information provided to both producers and consumers.[64] As one study concluded:

> "What is clear is that regulators can design regulation such that it minimizes the compliance burden on firms while maximizing the probability that the compliance innovation will be successful. Regulation should be flexible, allowing the firm and the market to decide the optimal path to implementation. Regulation should also be expedient—both in its implementation and execution—and unambiguous, minimizing the uncertainty facing firms when bringing new products or processes to the market. Regulators should also jump at opportunities to reduce information asymmetry in the market, or even to provide expert knowledge in collaboration with industry in order to aid the innovation process. And regulators should be cognizant of the trade-offs between the sudden enactment of stringent regulation versus the gradual increase of stringency over time. The most elementary lesson, however, is that, regardless the impact of regulation on innovation in general, if regulators simply place innovation at the forefront of their policy analysis along with distributional, fairness, and environmental concerns, then the United States will undoubtedly see a marked and sustained improvement in its innovative potential."[65]

Three factors that bear most importantly on the impact of regulation are the stringency of the regulation, its flexibility, and the information provided to both producers and consumers.

V. GENERATING INNOVATION

Generating innovation is necessarily an uncertain process since, by definition, innovation is something new—not necessarily a black swan but often different enough to be less than obvious at the outset. As the United States is, in fact, a highly innovative society, perhaps the first rule should be "do no harm." Particularly as policies are adopted for reasons where there is not a focus on innovation, there should be some regard to the potentially negative impact that they could have on innovation. Government budget cutting and market or regulatory constraints on corporate risk-taking are examples that can have important consequences for innovation. But beyond the principle of "do no harm," there are five key approaches that can positively increase the ability of the United States to innovate as a society.[66] These are enhanced deployment of the "cluster model" for innovation which engages the public, private, and nonprofit sectors jointly;

imposition of requirements on firms to protect the welfare of society or the environment. Typically, social regulation seeks to correct a market externality. Some examples of social regulation are environmental controls, health and safety regulations, and the regulation of advertising and labeling." Stewart, op. cit., p. 7.

64 Stewart, op. cit., pp. 4-6.

65 Ibid. Expedient, unambiguous regulation will minimize uncertainty and thereby reduce risk for decision-makers.

66 "The economic world is unlikely to become simpler. But we may rise to the challenge better if we think about both the social and institutional support that helps make complex collaborations possible—and the simple modular engineering that makes complex collaborations unnecessary." Tim Harford, "Teamwork Gives Us Added Personbyte," op. cit.; Also, Tim Harford, http://www.ft.com/intl/cms/s/0/d8270fda-152e-11e5-a587-00144feabdc0.html.

greater government focus on innovation; increased support for innovation by corporations; expanding the spectrum of entrepreneurs; and maintaining the diversity of ideas and approaches necessary for innovation while expanding the synergies between and among the multiple elements of the innovation landscape, including increasing the permeability between the national security agencies and the private sector.

A. Enhanced deployment of the cluster model

As the discussion above demonstrated, innovation is not a solitary process. Moreover, as innovation in a particular field moves past basics, diverse capabilities are increasingly needed to achieve next steps. Furthermore, often cross-disciplinary capabilities are required. "Clusters" can bring together the multiple streams of knowledge often critical to innovation. Clusters do not have one form. They can be within a single organization or across many; they can be formal or informal. They can be private, public, or a combination. Expanding the deployment of clusters that create collaborations among the best minds in the private sector, academia, other nonprofits, and government in key areas would improve the potential for innovation.

> Innovation is not a solitary process. Moreover, as innovation in a particular field moves past basics, diverse capabilities are increasingly needed to achieve next steps.

Two good approaches that will enhance the clusters models already existent would be to expand applied technology nonmanufacturing clusters involving government, private sector, and nonprofits to important R&D areas not yet covered or that would benefit from increased focus; and to expand the NNMI manufacturing cluster model beyond the current seven centers and create activities such as manufacturing testbeds, prototyping production capabilities, and prototype foundries in selected cases.

1) Expand nonmanufacturing applied technology R&D clusters.

As discussed above, a key factor for innovation is the opportunity to bring together multiple capabilities. Numerous entities have recognized this value and have encouraged or established "clusters" where potential innovators can come together. Clusters can be found in universities, in corporations, and in government. Bell Labs, Xerox PARC, and Lockheed's "skunk works" are corporate examples; the National Network for Manufacturing Innovation (NNMI), the National Science Foundation's Engineering Research Centers, and the Department of Energy's Energy Innovation Hubs, each discussed above, are examples of government encouragement of the cluster approach; and NIH and the laboratories of the Defense and Energy Departments are government examples. A key element to continue the promotion of innovation in the United States will be to expand the cluster model to the nonmanufacturing sector, in areas where it largely is not now covered or which would benefit from increased focus.

The general approach is reasonably well-established and can follow a model such as the National Science Foundation's Engineering Research Centers or the National Network for Manufacturing Innovation. Indeed, the President of MIT has recommended:

> "To create a new way of supporting the first stage—from idea to investment—a coalition of funders from the public, for-profit and not-for-profit sectors could work together to establish "innovation orchards." These would provide what universities alone cannot: the physical space, mentorship and bridge-funding for entrepreneurs to turn new science into workable products, up to the point that they meet venture capital's five-year threshold for the journey from investment to an impact on the market. This would make investing in tangible or tangible-digital hybrid innovations no riskier than investing in the purely digital."[67]

The key is to select, organize, and fund additional arenas. Although collaboration in general is beneficial for technological R&D, not all forms of collaboration accelerate technology advancement significantly. The cluster model generates collaboration in a manner that promotes innovation.

67 L. Rafael Reif, "A better way to deliver innovation to the world," *Washington Post*, May 22, 2015, https://www.washingtonpost.com/opinions/a-better-way-to-deliver-innovation-to-the-world/2015/05/22/35023680-fe28-11e4-8b6c-0dcce21e223d_story.html.

It does this by concentrating on key incentives for collaboration, which include the following:

- Bringing together government, industry, and academia to ensure that the best minds are involved. Excellent individuals seem to make a big difference to the ultimate breakthroughs; it is crucial to have such individuals involved.

- Establishing a unifying focus, so that the cluster will create the closer collaboration that accelerates breakthroughs. This focus must not be too constraining to the R&D directions; it must allow the alignment that enables key researchers to benefit from each other's research.

- Creating a desire and incentive for industry and academia to be part of the collaboration group.

From the authors' perspective, several new technology areas would be of significant consequence. These include quantum computing, artificial intelligence, human augmentation, nanotechnology, synthetic biology, genomics, Alzheimer's research, and cyber security. However, an article such as this would not be the appropriate place to make such choices. Rather, we recommend that the President's Council of Advisors for Science and Technology undertake to review and make recommendations with input from the private sector and government organizations such as DARPA and NIH. We would encourage other groups to create similar efforts in conjunction with, or in parallel to, a PCAST effort, including discussion by relevant committees of Congress. Ultimately, the decision would rest with the President and the Congress.

2) Expand manufacturer "cluster" model to include the establishment of manufacturing research centers, testbeds, prototype foundries, and even production prototyping capabilities in selected key areas. The National Network for Manufacturing Innovation is currently leading the establishment of expanded research efforts for manufacturing. This recommendation recognizes that more can usefully be done and follows from, but expands somewhat, recommendations in the report of the Advanced Manufacturing Partnership for PCAST. That report recommends:

> "the creation of manufacturing centers of excellence (MCEs) that . . . are research laboratories, funded and operated jointly by industry and universities, to invest in basic research that responds to a particular manufacturing challenge, such as critical materials reprocessing or bonding of composite structures. . . . These manufacturing centers of excellence could be co-located within U.S. regions shared with related Manufacturing Innovation Institutes, when feasible and advantageous to accelerated manufacturing technology maturation within the institutes."[68]

The report also recommended the establishment of "manufacturing technology testbeds." It noted that such testbeds can "provide access to equipment and facilities designed for the testing and demonstration of new technologies, [which] will enable evaluation, development, demonstration, and customization services to small, medium, and large enterprises, and vendors for technologies that are at later stages of development."[69]

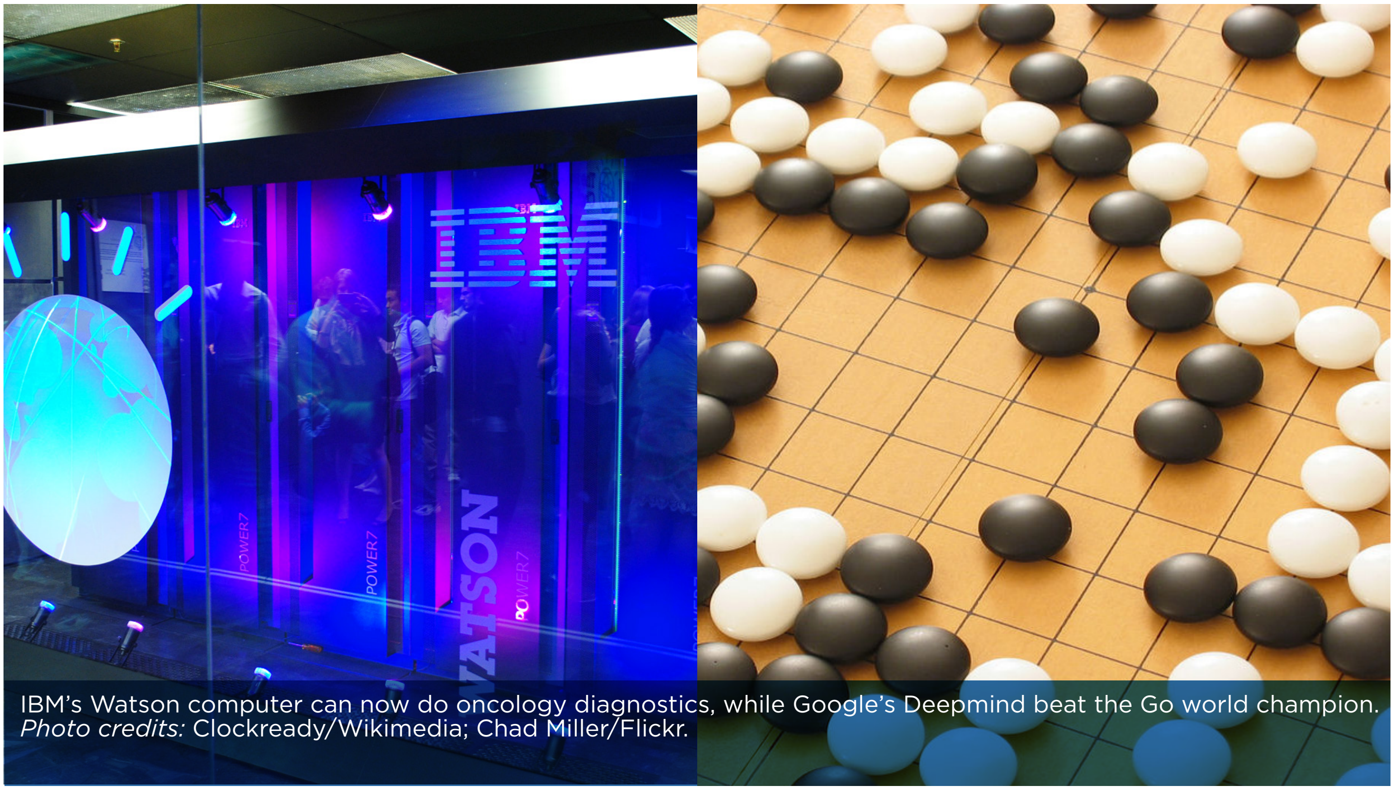
Seven Integrated Manufacturing Institutes (IMIs) exist today thanks to NNMI—an additional two are pending. A total of somewhere between fifteen and forty-five may be created in the next ten years. Each of these enhances a manufacturing area that can accelerate the introduction of innovative products. One of the best ways to approach a manufacturing cluster collaboration is to continue, or accelerate, the NNMI's deployment of manufacturing institutes.

Additionally, manufacturing testbeds and prototyping centers may provide capabilities that are highly beneficial to product innovators. Manufacturing technology is an evolving capability that enables incredible new technologies to be realized into products and systems at an affordable cost. At higher stages of maturity, Manufacturing Readiness Level (MRL) greater than seven, manufacturing lines can be highly complex and often unique and proprietary to a company. However, before it reaches that stage, simpler prototypes begin to congeal the ideas and lead to manufacturing breakthroughs that enable cost affordable solutions. This could be true for the production of small products, such as new carbon nanotube circuitry, or synthetic biological systems manufacturing, as well as for the production of large products that need new materials/coatings or advanced automation concepts.

Such efforts are where manufacturing technology testbeds can enhance the evolution of new products. Isolating the uncertainties in manufacturing methods and establishing the framework for statistical

68 PCAST, Advanced Manufacturing, op. cit., pp. 4-5.

69 Ibid.



IBM's Watson computer can now do oncology diagnostics, while Google's Deepmind beat the Go world champion. *Photo credits:* Clockready/Wikimedia; Chad Miller/Flickr.

control will be crucial to new manufacturing. Testbeds could dramatically shorten the timeline and expense for doing this. They could provide a place where entrepreneurs and companies could test and refine their manufacturing process ideas without having to build their own facility at a high (and sometimes prohibitive) cost. These would be focused at MRL six-seven and would be general in nature—examples might include nano-circuitry manufacturing in new nanomaterials or composite layup tools for testing new types of composite manufacturing.[70]

The expanded areas would follow on a review for selected key arenas as recommended by PCAST with input from the private sector and government organizations such as DARPA and NIH.

B. Greater government focus on innovation

Past government involvement in innovation has had a significant effect on US leadership in innovation as the discussion of funding, government projects, and the government research-private sector development model show. Continued focus on innovation will be necessary to sustain this innovation leadership. However, the early years of the twenty-first century have seen increased efforts by other nations to compete in innovation and a softening of federal R&D funding. There are three critical ways to enhance innovation through greater government effort: first, to increase funding for basic research and development; second, to increase access to international research and development; and third, by expanding government projects into key new areas. The first two are foundational and provide support to the United States' scientific and technology knowledge capability that is so critical to future innovation. The third stimulates innovation in key-focused areas through establishing purposeful projects that address key needs or issues for the country, in the same way that past defense projects helped usher in whole new technological innovations.

3) Increase federal funding for research and development to minimally one percent of GDP, with approximately one-half to go to basic and advanced research.

One of the fundamental challenges for future innovation in the United States will be to maintain adequate levels of funding for basic research and development. By definition, such basic R&D is not

70 Testbeds of this type will be unique to the type of manufacturing technology being developed, and a testbed may not work for all manufacturing technology concepts.

outcome oriented in the sense of seeking to bring a product or service to market. However, essentially no product innovation can go forward without the basic R&D well established to support it. As noted, the CBO has stated, "Economic studies have shown that federal support for R&D—particularly early-stage research—has long been very important in promoting innovation."[71] Indeed, per the CBO, "Some economic analysis suggests that the benefits from R&D would justify much higher spending on R&D and, in particular, much higher spending on basic research."[72]

For most years from 1976 to 2010, federal funding for research and development was above or near 1 percent of GDP.[73] Since 2011, however, this has not been true, with the percentage dropping to an estimated approximately three-quarters of a percent in 2015, a decrease of about nine percent in dollar terms from 2010.[74] Moreover, federal R&D—and therefore basic R&D—is very much at risk in future years. Much of that is a result of budgetary pressures. As the same CBO study notes,

> "However, in an effort to limit overall federal spending, policymakers have placed caps on most discretionary funding, a category of the federal budget that includes appropriations for R&D . . . . If policymakers choose to maintain spending for R&D at its historical share of total discretionary spending, then federal R&D would be expected to shrink significantly relative to the size of the economy. . . . CBO projects that in the 2020s DoD will not have the budgetary resources to fund its current plans, so that sustaining or increasing R&D would require disproportionate cuts to other areas. Similarly, about half of the nondefense portion of discretionary spending is for investment of some kind, whether R&D, education . . . or infrastructure. Increasing funding for R&D would put greater budgetary pressure on other categories of federal investment or on nondefense discretionary activities that do not constitute investment."[75]

71 Congressional Budget Office, Federal Policies and Innovation (November 2014), Op. cit, p. 1 (Summary).

72 CBO, op. cit., p. 13.

73 American Association for Advancement of Science, Historical Trends in Federal R&D, Trends in Federal R&D as Percentage of GDP, http://www.aaas.org/page/historical-trends-federal-rd.

74 Ibid.; See also, Eduarto Porter, "American Innovation on Weak Foundation," *New York Times*, May 15, 2015, http://www.nytimes.com/2015/05/20/business/economy/american-innovation-rests-on-weak-foundation.html.

75 Congressional Budget Office, Federal Policies and Innovation (November 2014), op. cit., pp.13-14.

For a nation that seeks to maintain or enhance innovation, such limitations on basic R&D spending is a very bad idea. In order to increase the prospect of future innovation, at a minimum, federal R&D budgets should be maintained at current real levels. But a better result would be to increase those budgets to approximately one percent of GDP as the medium- and long-term results are highly likely to benefit the country as a whole. Increasing basic and advanced research funding to levels of approximately half of the total would be especially invaluable.

4) Expand access to international research and development.

Although the focus of this paper is expanding innovation inside the United States, innovation is built on a foundation of basic research that is becoming increasingly international, and accessing that international knowledge is ever more important. Even defense and national security, which have historically benefited, and will continue to benefit, from basic research in the United States, need to improve the ability to access the increasing amount of basic research done outside the United States. The value of international research arises not only in the areas most closely connected to national security but also in other critical arenas such as health. As one well-placed venture capitalist has stated, "I do wonder what America's relative place will be, because so much of the dynamism in the world of technology is now taking place outside of the United States, and people here are just not aware of the scale of the achievements or the extent of ambition of the entrepreneurs there."[76] Similarly, the Defense Science Board noted the importance of "keeping abreast of basic research conducted around the world,"[77] and proposed:

> "The fraction of the DOD basic research program that is devoted to supporting overseas efforts is not commensurate with the inexorable rise in the fraction of the world's basic research being conducted outside the United States. The task force recommends the establishment of research entities overseas, which might be a satellite of a DOD laboratory, might involve a relationship with a university or other research institution overseas,

76 Conversation with Michael Moritz, "Much Ventured, Much Gained," *Foreign Affairs*, December 15, 2014, January/February 2015, p. 39, https://www.foreignaffairs.com/interviews/2014-12-15/much-ventured-much-gained.

77 DSB, "Report on Basic Research," Office of the Secretary of Defense, op. cit., p. xi.

may involve government-to-government partnership, or other alternatives. Further, the task force recommends that DOD laboratory directors increase the locations at U.S. Service laboratories where foreign researchers can work on basic research, and that DOD basic research office directors should support DOD laboratory and U.S. university researchers to do work overseas."[78]

As the task force suggested, organizing coordination with key entities outside the United States, including through the establishment of collocated research centers in selected key countries at universities and similar entities, would have highly beneficial effects for the United States.

5) Expand government efforts into key focused arenas, through projects that create innovative concepts, systems and/or products that address major issues or needs for the United States. These projects likely will expand innovation using technologies such as quantum computing, artificial intelligence, human augmentation, nanotechnology, synthetic biology, genomics, Alzheimer's research, and cyber security as recommended by the governmental advanced research projects agencies and NIH (with input from the private sector that could be organized through PCAST). However, the emphasis should be on stimulating innovation; this can be enhanced through establishing a focus on major problems to be solved, providing initial funding for R&D, and creating a basis for investment by private industry through the promise of a potential market.

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The government has historically had significant success in its government project efforts. Not only have these projects created key capabilities for government interests, such as national security, many have expanded their innovative potential to shape major societal structures and yielded huge economic and social benefits. As noted above, computers, the Internet, and semiconductors are all examples of successful projects, as were more focused efforts such as the Manhattan Project and the landing on the moon. American innovation should continue these types of government projects as one key component of enhancing innovation leadership. The Department of Defense can be expected to continue national security focused efforts so long as it has sufficient funding. However, broader funding should also be continued in agencies like the multiple advanced research project agencies and laboratories run by DOD, the Intelligence Community, and the Energy Department, as well as in the health arena generally under the auspices of the National Institutes of Health.

There are several specific areas where the government could play an important role. As noted above, these include Alzheimer's research, quantum computing, artificial intelligence, human augmentation, nanotechnology, synthetic biology, and cyber security. The common ground of each of these is that the technology is generally at early days, and the market has yet to bring forward highly satisfactory solutions. Successful government projects that utilize and stimulate these technologies through tackling a particular problem or need could potentially make very significant differences for American society at large. The use of Grand Challenges as a means for generating innovation for some or all of these areas could be highly beneficial and should be expanded. The Office of Science and Technology Policy could coordinate this effort for a new administration.

Breakthroughs often occur when government, academia, and industry are brought together to focus attention on a given problem. These breakthroughs could then, of course, be built upon by the private sector. However, as also noted above, in a report of this type, we do not propose to pick the actual areas of concern or the actual technologies involved. Rather as before, we propose that recommendations be made by the governmental advanced research projects agencies

78 DSB, op. cit., p. xiii.

and NIH (with input from the private sector that could be organized through the President's Council of Advisors for Science and Technology).[79]

In a discussion of this type, there is often raised the concern that the government is not good at picking winners. The success of the many government projects noted above belies that suggestion. (Moreover, the government often succeeds by picking the problem and utilizes the private sector to generate the solution, another reason to use Grand Challenges.) Additionally, the fact that some government projects do not succeed is not a reason for the government to forgo such efforts. In the private sector, for example, venture capital funding is undertaken even though the expectation is that they fail more often than not—and depending on the analysis, fewer than one in ten may be "home run" successes.[80] The government has done at least as well as that standard—and often can be expected to do better.

One final point: The Department of Defense and other national security agencies are currently heavily focused on seeking to generate highly innovative capabilities. The DOD effort is called the "Third Offset" strategy. As described by the Deputy Secretary of Defense, "This third offset . . . is focused on great power, trying to deter great power wars, . . . it's really focused on the advanced capabilities that Russia and China can bring to bear. The whole purpose is to convince them never to try to cross swords with us conventionally."[81] There are particular arenas that the DOD Third Offset emphasizes including "human-machine collaboration," "artificial intelligence and autonomy," "assisted human operations" (e.g., robots),[82] "human-machine combat teaming" (combining manned and unmanned systems), "autonomous weapons," and "put[ting] them on a single network."[83] DOD is more than capable of picking its areas of emphasis.[84] However, the broader innovation endeavor described in this report can create an innovation landscape that will effectively support that effort. An important element will be to increase the interface between national security agencies and the private sector as recommended in section ten below.

C. Increased support for innovation by corporations

Corporations are an important engine for innovation. In this regard, it is particularly useful to recall that innovation does not end with invention but requires getting to market, a capability for which corporations are explicitly designed.[85] How corporations respond depends very much on the context in which they make their decisions. One study put it this way:

> ". . . [A]nalysis shows that innovation needs strong support to be able to deliver on its promises. Indeed, inventions do not become

79 One additional area that PCAST and other innovation-oriented organizations should consider is process-oriented innovation. Such developments as the container revolution, charter schools and companies like Federal Express have had important consequences for American society and the world. There are numerous challenges facing the United States that seem to call for better process efforts. For example, the DOD and the State Department have faced the difficult tasks of building partner capacity including militaries, police, justice and general good governance in multiple countries and can expect such challenges in the future. How to improve results is a key challenge for national security.

80 See Deborah Gage, "The Venture Capital Secret: 3 Out of 4 Start-Ups Fail, *Wall Street Journal*, September 20, 2012, http://www.wsj.com/articles/SB10000872396390443720204578004980476429190; Diane Mulcahy, "Six Myths about Venture Capitalists," *Harvard Business Review,* May 2013, "), https://hbr.org/2013/05/six-myths-about-venture-capitalists. ("many more venture-backed start-ups fail than succeed"); See Sarah Webster, Inside America's Bold Plan to Revive Manufacturing, p. 11, op. cit. ("For one, this area of research is considered high risk. Not every proven scientific idea for a manufacturing technology is scalable for the commercial market, in terms of repeatability, quality or cost. So this is an area where shortcomings, some of them insurmountable, are often exposed, and money is inevitably lost.").

81 Robert Work, Deputy Secretary of Defense," Reagan Defense Forum: The Third Offset Strategy," November 7, 2015, http://www.defense.gov/News/Speeches/Speech-View/Article/628246/reagan-defense-forum-the-third-offset-strategy.

82 The National Science is also focusing on robotics with the National Robotics Initiative, http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=503641&org=CISE.

83 Robert Work, Deputy Secretary of Defense, "Reagan Defense Forum: The Third Offset Strategy," November 7, op. cit., 2015.

84 There are multiple task forces that regularly make recommendations to the DOD for specific types of efforts. For example, the Defense Science Board has stated (Defense Science Board, Technology and Innovation Enablers, supra, p. x): "Specific areas of emerging technology that are considered to have significant disruptive potential in the 2030 timeframe, either individually or by enabling established areas of research in new ways, include: large-scale storage, manipulation, and analytics for data, as well as significant changes in cyber capabilities and vulnerabilities; quantum information sciences; the biological sciences; and research in power and energy. For example, as data become more available and the associated capabilities to access, manage, and analyze them progress, the ability to monitor the behavior of individuals and groups will grow with the potential for predictive models and more effective engagement during periods of instability."

85 Without trying to overstate, corporations may also have advantages as innovation proceeds in a particular arena, requiring understanding and incorporating prior knowledge from diverse arenas. See "Now and then," Economist (April 25, 2015), discussing how some innovation proceeds by discovery and some by combination of prior knowledge, http://www.economist.com/news/science-and-technology/21649448-patent-records-reveal-way-inventions-are-made-has-changed-over.

> innovations until they are deployed at scales sufficient to have an impact, and there are many non-technical barriers that can prevent very cost-effective solutions from playing their role. We must therefore adopt a systems perspective and recognize that technology innovation will only occur if the right policy signals, as well as market and regulatory frameworks are in place to foster environments conducive to attracting the required levels of investments."[86]

As the foregoing states, corporate innovation depends on the right policy signals. In today's environment, the corporate propensity to innovate could be significantly enhanced if market penalties for risk-taking in support of innovation were reduced; if financing in support of such risk-taking was increased; and if regulators had to take account of the consequences for innovation in determining how to establish market and social regulations.

6) Authorize creation of tax-advantaged subsidiaries and investments, including tax-free technology bonds, focused on innovation in critical areas as recommended by PCAST (with input from the private sector as well as government organization such as the DARPA and NIH).

As discussed above, while the invention of a new technology will require the breakthrough efforts of highly creative researchers, the potential of innovative breakthroughs may linger in technology concepts, or in market niches, until the technological breakthrough diffuses into the market. To accomplish the necessary diffusion, large corporations are one of the institutions that have the ability to introduce new capacities that link up with public demand by generating the required changes in market and societal processes. While, as the data discussed above shows, corporations do finance applied R&D, enhancing innovation, including diffusion, into critical areas could be furthered by incentivizing market return. Putting it another way, there could be significant benefits from incentives that make a traditional "business school" calculation of net present value of an innovative effort turn out positive with an acceptable risk and time horizon, and generate a positive Wall Street investor assessment of the endeavor.

86 International Energy Administration, "Tracking Clean Energy Progress 2015," p. 4, http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress_2015.pdf.

To accomplish innovation, corporations necessarily have to undertake some risk. Resources—particularly highly talented personnel—have to be dedicated to the effort, and changes to known processes that heretofore have been applied through established organizations likely are required. Both the risk and the unfamiliarity of innovation thus present a barrier to an enterprise, especially where earnings are based on stable continuing lines of business.

To change this calculus and incentivize corporate innovative behavior from technology to diffusion, one approach would be to utilize positive government regulation in the tax, accounting, and securities arenas. Specifically, legislative and regulatory authority could be enacted which allowed/incentivized corporations to form a new type of innovation subsidiary—one that could have outside investment and could trade stock independently of the parent corporation, but would be synergistically tied to the parent and would go to the marketplace utilizing the parent corporation's capabilities. If effectuated properly, such a subsidiary could focus on transformational innovation; it could have a longer time frame; it could utilize the parent's market acumen for promotion of the transformational technology; it could achieve stock pricing like a well-funded start-up; it could share success with the parent; and the parent could defer a significant amount of the risk.

Legislation and regulation designed to accomplish that result would include the following incentives: First, during the initiation period before successfully achieving innovation, the parent could receive a tax credit for the full research and development efforts (perhaps including the initial diffusion into the market) of the subsidiary—thus making the net present value calculation positive for this risky innovation. Second, the corporation could be authorized to issue tax-free technology bonds, thereby lowering the cost of finance. These might be particularly attractive if covered by the parent and after a period of time convertible into stock of the subsidiary. Third, the subsidiary could be relieved of quarterly reporting requirements, thus helping to give it a longer-term focus. Fourth, the subsidiary's stock could be subject to special capital gains treatment so that if held for a longer period, perhaps on a sliding scale, investors would benefit—and a longer term focus would be created.[87]

87 Tanden and Effron, ("How To Foster Long-Term Innovation Investment," op. cit., p. 6.) among others, have made such a proposal: "A sliding-scale capital gains tax that determines the rate charged to investors in accordance with the holding period of the security has been considered at least as far back

Not every corporation would be entitled to such support. A good way to start would be to require such a subsidiary to have an established arrangement with one of the government ARPAs or NIH—perhaps working on designated projects—or, alternatively, Congress could itself list key arenas where such efforts would be most desirable. For example, projects with significant societal benefit might be a good place to start, such as Alzheimer's research, artificial intelligence, or quantum computing. Again the PCAST could make recommendations as to which arenas should be highlighted, though ultimately it would be up to the President and the Congress to decide. Further, to maintain its regulatory advantages, the subsidiary could be required to meet certain criteria during perhaps a ten-year term, such as sufficient R&D and/or marketing efforts in connection with the innovative goal. Creating such an approach could prove to be an important initiative for the new administration.

7) Authorize "innovation assessments" by regulators.

In one of the studies discussed above, the analysis concluded: "The most elementary lesson, however, is that, regardless the impact of regulation on innovation in general, if regulators simply place innovation at the forefront of their policy analysis along with distributional, fairness, and environmental concerns, then the United States will undoubtedly see a marked and sustained improvement in its innovative potential."[88] A comparable OECD study put some specifics into the concept of regulatory assessment for innovation, stating:

> "This review . . . leads to several general conclusions on how to improve the positive regulatory effects on innovation without jeopardizing the original regulatory objectives [including] [1] Understand regulation/technology linkages. . . . [2] Introduce competition. . . [3] Streamline regulations. . . . [4] Use technology-driving approaches [and] [5] Harmonize internationally."[89]

The basic point of setting forth these criteria, however, is not to write the specific regulations in this report, but rather to demonstrate that such an innovation assessment approach is both reasonable and feasible. Such an effort could be started if the President and the Congress would authorize regulators to include an innovation assessment element in conjunction with the establishment of regulations that reach the level of major federal actions significantly affecting national markets. Industry could be encouraged to provide input, and an organization like the National Science Foundation or the PCAST could be authorized to provide additional analysis for regulators' use. Initially, at least, we would not go as far as to suggest a requirement with the potential impact of the National Environmental Protection Act, which actually can bar some regulations' implementation, but rather allow regulators the discretion to take account of the available input. The recent discussions between industry and the Department of Transportation regarding regulations for self-driving cars could be an initial model.[90]

One additional factor that might be evaluated is to consider the informed risk taking by consumers as a component of innovation. Not all consumers would necessarily fit in that category, but government as a customer might—as could groups within the private sector and/or the public. An analogous situation arises in the securities field, where certified investors are allowed to make certain risky investments—and the recent development of crowd sourcing will expand the circumstances under which investors may provide funds.[91]

In short, government policy should seek to establish a proper balance between protecting the public from harm, and enabling the public—or specified portions—to accept risks in search of potentially better outcomes. When an innovation provides potential for better outcomes, the policy should

as the 1980s. If properly structured, the tax could provide ample incentive for investors to take a longer-term view of the firms in which they invest and ensure these interests are clear to asset managers. This policy would provide a sustainable balance between rewarding long-term growth initiatives and modestly discouraging trade-offs made for short-term gains." The paper cites Daniel Feenberg and Lawrence H. Summers, "Who Benefits from Capital Gains Tax Reductions?" In Lawrence H. Summers, ed., *Tax Policy and The Economy*, vol 4. (Cambridge, MA: MIT Press, 1990), http://www.nber.org/ chapters/c11570.pdf.

88 Luke A. Stewart, The Impact of Regulation on Innovation in the United States: A Cross-Industry Literature Review Information Technology & Innovation Foundation, June 2010, p. 6, http://www.itif.org/publications/2011/11/14/impact-regulation-innovation-united-states-cross-industry-literature-review.

89 Organisation For Economic Co-Operation And Development, *Regulatory Reform And Innovation*, p. 8.

90 Bill Vlasic, "U.S. Proposes Spending $4 Billion on Self-Driving Cars," *New York Times,* January 14, 2015, http://www.nytimes.com/2016/01/15/business/us-proposes-spending-4-billion-on-self-driving-cars.html?smid=nytcore-ipad-share&smprod=nytcore-ipad&_r=0.

91 Jack Newsham, "SEC opens door to startup investing for all," *Boston Globe*, October 30, 2015, https://www.bostonglobe.com/business/2015/10/30/sec-opens-door-startup-investing-for-all/IT3ibqse1sa9tFhlamNa6L/story.html.

try to eliminate bad outcomes, but still allow for progress.[92] In today's Internet world, the public has greater access to information than ever before. Generalizing, to encourage innovation, regulatory policy should evolve to reflect the state of an evolving public understanding as a result of the greater availability of information.[93]

D. Encourage Greater Development of Entrepreneurs

Innovation requires risk-taking and talent. As discussed above, one of the more useful cultural developments in recent years has been the willingness of philanthropists to take risks with their fortunes in pursuit of innovation. The key to results is having sufficiently talented people to turn the money spent into useful results. To continue this process, two key steps would be to further develop the philanthropic culture in support of innovation and to ensure that the pipeline of talent is given sufficient support.

8) Encourage the increased efforts of "philanthropic entrepreneurs" in innovation, especially through social and cultural incentives, building on the model of the Giving Pledge, the Science Philanthropy Alliance, the use of prizes, and similar efforts.

Elements that may enhance the value of philanthropic entrepreneurship include an increased focus on strengthening the social and cultural norms for large fortunes to be provided in the service of society; a capacity to give some direction in the scientific arena for good uses of those funds; and the ability to use prizes to cause talent to respond.

Human behavior responds to societal and cultural norms, and one of the factors that may have encouraged many of today's philanthropic entrepreneurs is the Giving Pledge originated by Bill and Melinda Gates and Warren Buffett. The Giving Pledge is a nonbinding moral commitment to which billionaires can agree to give at least half their fortunes away during their lives or by will. At least one hundred billionaires have signed the pledge.[94]

The gift of such large fortunes can support the establishment or sustainment of scientific institutions like universities or other nonprofits, as the discussion above demonstrated. Wealthy persons are, of course, entitled to dispose of their money as they choose, and there are many very worthwhile philanthropic efforts. In addition to the support of institutions, there are some efforts to encourage such giving with a focus on particular scientific problems. Certain of the philanthropic entrepreneurs have made their own choices. More recently, Gates has led with pledges for research and development regarding climate change.[95] One way to encourage greater efforts toward innovation might be to include a relationship to innovation in the Giving Pledge, at least as an option. Another relatively new effort is the Science Philanthropic Alliance, which was created to coordinate philanthropic giving and key basic research problems. The Alliance's stated purpose is set forth as follows:

- "Basic scientific research provides the foundation for discoveries that are critical to our long-term economic growth and societal well-being, and philanthropic institutions and individuals have a crucial role to play in supporting it. The Science Philanthropy Alliance was founded by six funders committed to basic, discovery-driven scientific research working together to increase private investment in fundamental research and to ultimately help ensure a better and more prosperous future."[96]
- "By serving as an impartial adviser to philanthropists, promoting collaboration among those who are interested in this vital stage of scientific discovery, and bringing together donors and top scientists, the Science Philanthropy Alliance aims to substantially increase philanthropic funding for fundamental

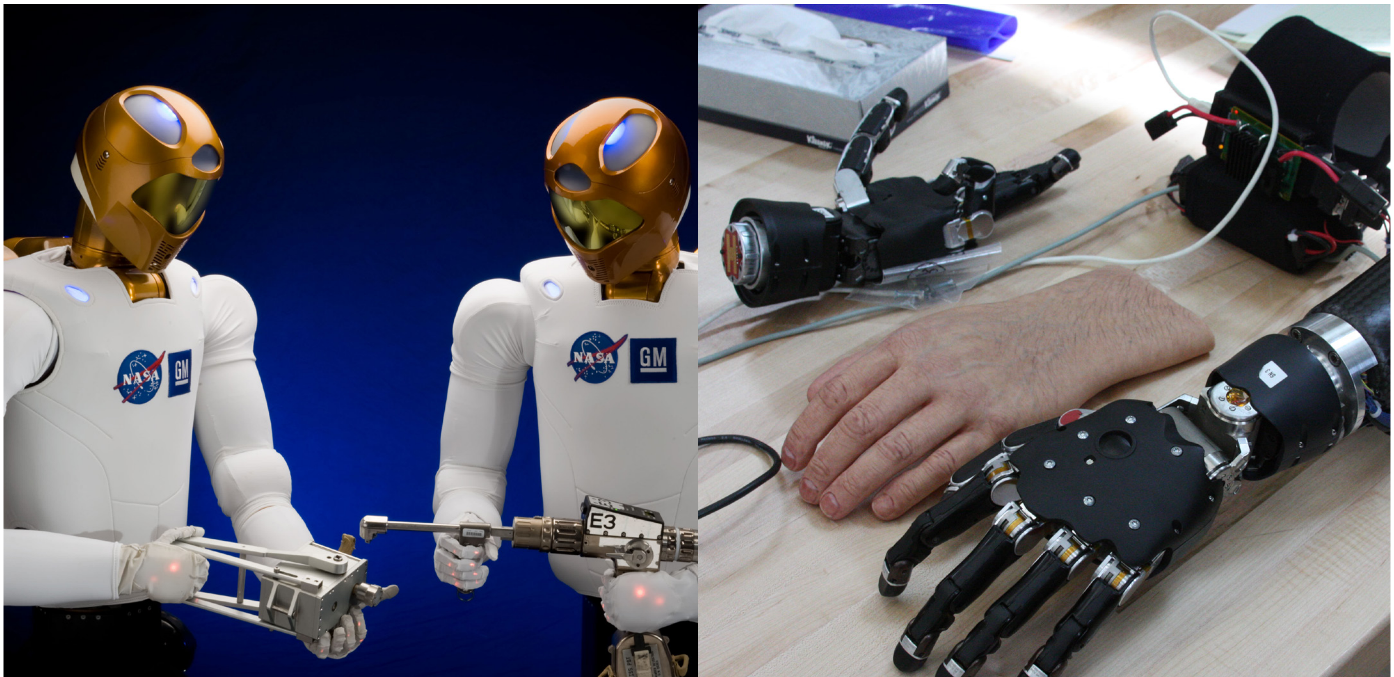
92 An example of the challenges is the debate surrounding a gene-editing technique. See Heidi Ledford, "CRISPR, The Disruptor," *Nature,* June 2015, p.20, http://www.nature.com/news/crispr-the-disruptor-1.17673.

93 One additional important effort that is beyond the scope of this paper is efforts by the government to protect innovation developed by American companies. This includes ensuring the rule of law, maintaining appropriate international standards, and helping companies protect against industrial espionage. A great deal of such efforts involves dealing with China. The new administration should develop appropriate policies and effective implementation measures in these regards.

94 The Giving Pledge, http://givingpledge.org/; see Jackie Wattles, "10 more billionaires join Buffett-Gates Giving Pledge." http://money.cnn.com/2015/06/02/news/companies/giving-pledge-billionaires-buffett-gates/. The pledge does not bind signatories to any particular philanthropic effort.

95 Coral Davenport and Nick Wingfield. "Bill Gates Takes On Climate Change with Nudges and a Powerful Rolodex," *New York Times*, December 8, 2015, http://www.nytimes.com/2015/12/09/business/energy-environment/bill-gates-takes-on-climate-change-with-nudges-and-a-powerful-rolodex.html.

96 Science Philanthropy Alliance, http://sciencephilanthropyalliance.org.



Robotics and complementary advances have progressed to allow humanoid robots to perform mechanical tasks such as the use of tools and to provide replacement capabilities for critical human functions like the human hand. *Photo credits:* National Aeronautics and Space Administration/Wikimedia; US Navy/Flickr.

> research and create a community of funders for discovery-driven scientific inquiry."[97]

Coordination of research by efforts such as the Science Philanthropy alliance may prove useful.

In addition, there are now numerous prizes awarded by various institutions supported by philanthropy, and the establishment of prizes may also be an effective way to focus philanthropy on key science problems. One review found that the "power of prizes to spur innovation has been rediscovered by a new generation of wealthy individuals. . . . [O]ffering a prize can get . . .a bigger bang . . .than traditional giving. . . . [A] carefully crafted challenge spurs spending by competing teams that can add up to many times the value of the prize."[98] One analysis similarly concluded that, "There is a growing consensus that awarding cash prizes for innovations is a more efficient process of promoting productive innovation. Prizes immediately benefit firms that successfully innovate without creating disincentives for rapid information sharing among innovative companies."[99]

The philanthropic entrepreneur is a relatively new phenomenon, yet one to be encouraged. It is hardly the first time that money has been put to the service of society. What we see today is the "Medici model," though in service of science rather than art. There is good reason to think that this Medici model will expand. As the model takes hold, it will increasingly be a norm for society, and people respond to such norms. As a recent World Bank analysis noted:

> "Individuals are social animals who are influenced by social preferences, social networks, social identities, and social norms: most people care about what those around them are doing and how they fit into their groups, and they imitate the behavior of others."[100]

A good deal more could be done. Expanding the conversation on social media would potentially generate added funding of various sorts.

97 Ibid.

98 Stephen Foley, "The Power of Prize Money Is Rediscovered to Spur Innovation," *FT Wealth*, September 2015, p.24, http://app.ft.com/cms/s/764866a2-56be-11e5-9846-de406ccb37f2.html.

99 Tanden and Effron, "How to Foster Long-Term Innovation Investment," op. cit., p.4. The analysis stated, "For example, the Xprize Foundation has awarded prizes to firms that have successfully created technologies to expand commercial space travel and clean up oil spills. The foundation has a number of currently active prize competitions." See, Xprize Foundation, "Prizes," http://www.xprize.org/prizes, last accessed June 2015."

100 World Bank, "World Development Report 2015: Mind, Society, and Behavior, Overview," p. 7, http://www.worldbank.org/en/publication/wdr2015.

Establishment of additional organizations along the lines of the Science Philanthropy alliance would have benefits. Increasing interaction with government institutions such as the advanced research projects agencies could help. Making clear that not every gift needs to be at the billionaire level would be useful; as the listing of the federal funding above makes clear, gifts of still significant but far smaller amounts can be highly consequential.

9) Encourage talent growth through the expansion of clusters as an attractive environment both for elite researchers and for the development of technical training through community colleges and online courses that lead to the creation of the necessary production and related skills.

Talent is obviously a key factor in generating innovation, but "talent" is not a self-defining word. The different types of talent both relevant and necessary to innovation are suggested by a recent study of the development of two drugs, where the authors found that "According to the networks of cited publications, [one drug—ipilimumab] resulted from research conducted by 7000 scientists from 5700 institutional affiliations over the course of 100 years, while [the other—ivacaftor] took 2900 scientists with 2500 different affiliations 60 years to develop."[101] While the first conclusion to draw is how many are involved, the study also determined that there were "elite performers" "who contributed disproportionately to the development of the drugs."[102] The analysis suggested that "Ascertaining—and then emulating—certain qualities of elite performers may be one way to accelerate discovery and propel scientists more rapidly down the path toward cures."[103] In short, there was a requirement for both the "many" and the "few."

It is not easy to generate the "few." However, given their existence, a reasonable hypothesis is that they may be attracted to contexts in which they can best perform their desired objectives. Clusters of elite researchers may be one of those contexts for many, if not all, of the elite researchers. It has long been the case that leading universities provided key thinkers a desirable environment, and innovation clusters may similarly be useful efforts.

The talent necessary to translate invention into innovation is key, and innovative businesses must work where such talent is available.

As the drug study above suggests, the few are not enough. Innovation is more than invention and requires multiple tasks and capabilities. The talent necessary to translate invention into innovation is key, and innovative businesses must work where such talent is available. As one analysis stated, "Simply said, global businesses invest where the talent exists."[104] However, the United States faces a particular talent problem, namely the need for the skills necessary for innovative production:

> "Technological developments in the manufacturing sector have outpaced workforce skills, and demographic shifts have combined to create a gap in the workforce the manufacturing sector needs. The Manufacturing Institute notes that the hardest jobs to fill are those that have the biggest impact on performance, that manufacturers depend on outdated approaches for finding the right people and developing their employees' skills, that the changing nature of manufacturing work is making it harder for talent to keep up, and that the widening skills gap is expected to take the biggest toll on skilled production jobs."[105]

The PCAST's Advanced Manufacturing Partnership has recommended that this issue is "best addressed through partnerships of committed and motivated groups of firms and educational institutions."[106]

The fundamental point is that education, both initial and, as necessary, retraining, is critical.[107] Some of this can be done by the "development of online training and accreditation programs eligible to receive federal support, for example through federal jobs training programs."[108] As has been noted:

101 See Science Daily, "100 years to find a cure: Can the process be accelerated?" September 24, 2015, http://www.sciencedaily.com/releases/2015/09/150924142659.htm.

102 Ibid.

103 Ibid.

104 PCAST, Advanced Manufacturing, p. 7, op. cit.

105 Ibid.

106 Ibid.

107 See generally, Alexi Monsarrat, "Training Our Future: Skilled Workers and the Revival of American Manufacturing," December 2013, http://www.atlanticcouncil.org/publications/reports/training-our-future-skilled-workers-and-the-revival-of-american-manufacturing.

108 PCAST, Advanced Manufacturing, p.9, op. cit.

"Community College level of education is the 'sweet spot' for impact on the skills gap in manufacturing."[109] Finally, because "apprenticeships are so integral to a tradesman earning a professional credential or accreditation, and because hand-on learning is of utmost importance for many careers in advanced manufacturing, the Advanced Manufacturing Partnership organized and piloted an apprenticeship program [which] . . . illustrated the importance of collaboration between community colleges and employers to deliver customized training that meets the unique needs of employers and provides flexibility to future employees."[110]

There are also good reasons to think that focusing on enhancing diversity will usefully expand the talent pool relevant to innovation. In the computer arena, the National Center for Women and Information Technology has done analyses that indicate the overall lack of representation of women.[111] There are also a variety of proposals for expansion.[112] Other areas have similar deficiencies and would similarly benefit both from greater women and minority participation.[113]

E. Expand synergy between and among the key elements of the innovation landscape but encourage diverse approaches so as to maximize the prospect of innovation

10) Expand the permeability between national security agencies and the private sector by revising the federal acquisition approach in order to support key innovative defense and national security projects including DOD's "Third Offset Strategy."

The Department of Defense and other national security agencies have always benefitted from innovation in the private sector. Historically, this has occurred most often in the so-called defense industrial base with companies like Lockheed Martin, Boeing, and Northrop Grumman. However, as the Secretary of Defense recently stated, "innovation is happening all over the country... And in some areas of technology, it's happening most quickly in commercial start-ups and in non-defense companies. Point is, DOD has to tap into all those streams of innovation and emerging technology, and it has to do so much more quickly."[114]

In order to accomplish this greater interaction, there is, as the Secretary of Defense has noted, an ongoing effort at "drilling tunnels through that wall that sometimes seems to separate government from scientists and commercial technologists – that wall, making it more permeable so more of America's brightest minds can contribute to our mission of national defense, even if only for a time, or on and off in the course of their careers."[115] To accomplish this, the DOD is seeking to "mak[e] ourselves open . . . and more agile, to work with start-ups, commercial companies, and small businesses in a way that is compatible with their business practices and their business needs."[116] One example of the effort is the "Defense Innovation Initiative-Experimental" which is part of the overall Defense Innovation Initiative[117] and includes the recent opening of a DOD office in Silicon Valley intended to increase communication and ultimately enhance the ability to work together.[118] Likewise, DOD is supporting several of the NNMI manufacturing clusters.[119] These efforts might be expanded by having the military services and the Office of the Secretary of Defense increase the use of "technology scouting" to seek out innovative opportunities throughout the economy.[120]

That goal of, and the initial steps toward, permeability is highly desirable, but there are significant obstacles in the form of legislative and

109 Ibid.

110 Ibid.

111 National Center for Women and Information Technology, "Women in IT: The Facts Infographic [2015 Update], https://www.ncwit.org/resources/women-it-facts-infographic-2015-update.

112 Paula Stern, "Diversity in Cybersecurity for Superior Outcomes," National Center for Women and Information Technology website, January 16, 2016, https://www.ncwit.org/blog/diversity-cybersecurity-superior-outcomes (including military to civilian pathway).

113 Bonnie Marcus, "The Lack Of Diversity In Tech Is A Cultural Issue," *Forbes,* August 12, 2015, http://www.forbes.com/sites/bonniemarcus/2015/08/12/the-lack-of-diversity-in-tech-is-a-cultural-issue/#384c51073577.

114 Ashton Carter, DARPA Future Technology Forum, op. cit.

115 Ibid.

116 Ibid.; see also the Defense Innovation Marketplace, http://www.defenseinnovationmarketplace.mil/.

117 Op.cit, http://www.defenseinnovationmarketplace.mil/DII_Defense_Innovation_Initiative.html.

118 Ibid.

119 See, e.g., photonics, http://manufacturing.gov/ip-imi.html#faq2; and additive manufacturing, https://americamakes.us/membership/membership-listing.

120 NIST undertakes technology scouting in conjunction with small and mid-sized businesses. See http://www.nist.gov/mep/services/innovation/tech-solutions.cfm. See also Report to the Congress, Information Technology Program, Center for Technology and National Security Policy, National Defense University, January 2006.

regulatory barriers to that end. Accordingly, it would be highly valuable for the DOD to establish a task force to draft proposed legislation and regulations that would allow for the kind of "permeability" between the private sector and the Department of Defense that innovation requires. It would be fair to say that increasing permeability could increase some risks in terms of access and dissemination of information. But in today's world, where so much innovation occurs outside the traditional defense industrial base, there are greater risks in not reaching out. Two key factors that should be considered would be allowing acquisitions that are nonuniform throughout the force but have significant potential, and considering how to allow commercial entities to maintain greater control over the intellectual property. Establishing a task force with a short deadline that could report simultaneously to the Secretary of Defense and the Congress would be a worthwhile endeavor.

Caveat: Maintain diversity

A fundamental conclusion from the analysis above is that innovation benefits from synergy. The efforts that the federal government has made with the various cluster activities should be expanded precisely to encourage that synergy. However, it is well to note that innovation, almost by definition, means often not marching in lock step. Diversity is a key factor including stepping away from the mainstream and striking out on a new path. In this light, we would caution against a recommendation that some others have made—namely, to create a national technology strategy. Such an effort is likely to exclude some of the diverse but ultimately very important innovative efforts. Robert Shiller, a Nobel Prize winning economist and himself an entrepreneur has put it this way,

> "[R]eal-life . . . convinces me that committees of experts, even at smart venture capital firms, will often not recognize real innovation. I think that America's business success through the decades has occurred because we have so many people with specialized knowledge who are willing to put their money, time and resources on the line for ideas that can't be proved to a committee."[121]

121 Robert J. Shiller, "Why Innovation Is Still Capitalism's Lodestar," *New York Times,* August 17, 2013, http://www.nytimes.com/2013/08/18/business/why-innovation-is-still-capitalisms-star.html.

Having multiple efforts rather than one is much more in keeping with the American character and competitive system. Simply by way of example, the proposals for innovation made by a well-regarded group such as the American Energy Resource Council differ greatly from those made by the Science Philanthropic Alliance—and each of those differ from reports from the PCAST. As this suggests, a multifaceted governmental approach can be useful. Indeed, even Professor Shiller noted that, while urging care, "At the same time . . . my experiences incline me to think that government-appointed committees of experts *can* help set the stage for an entrepreneurial culture, under certain limited circumstances."[122] In sum, while as much of the discussion in this report indicates, we strongly encourage the federal government to expand its efforts, we equally are opposed to any degree of single centralization. Innovation requires different thinking; that, in turn, requires independence; and that requires a light touch by the government. At the front of this report, we began with President Eisenhower's statement that "research has become central." We can close by his concomitant admonition, "The prospect of domination of the nation's scholars by Federal employment, project allocations, and the power of money is ever present and is gravely to be regarded."[123]

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122 Ibid.

123 President Dwight D. Eisenhower, "Military-Industrial Complex Speech," 1961, http://coursesa.matrix.msu.edu/~hst306/documents/indust.html. It is fair to note that, while we disagree, the PCAST has stated, "A national technology strategy outlining specific efforts and investments across the federal government and the private sector, and created and regularly updated with input from leading technologists across industry and federal labs, can optimize the nation's investment in manufacturing technology development." President's Council of Advisors on Science and Technology, "Report to the President: Advancing U.S. Advanced Manufacturing," October 2014, p. 3, https://www.whitehouse.gov/administration/eop/ostp/pcast/docsreports.

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