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Charles W. Wessner, Ph.D

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Contact information
Address: Edificio Expo. c/ Inca Garcilaso, 3. E-41092 Seville (Spain)
E-mail: jrc-ipts-secretariat@ec.europa.eu
Tel.: +34 954488318
Fax: +34 954488300

JRC Science Hub
https://ec.europa.eu/jrc

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Abstract
RIO R&I International Country Reports analyse and assess the research and innovation system, including the main challenges, framework conditions, regional R&I systems, and international co-operation.

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Foreword

The report offers an analysis of the R&I system in the United States for 2015, including relevant policies and funding. The report identifies the main challenges of the US research and innovation system and assesses the policy response. It was prepared according to a set of guidelines for collecting and analysing a range of materials, including policy documents, statistics, evaluation reports, websites etc.

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Executive summary

The United States economy is the largest and among the most dynamic and innovative in the world. The scale of the U.S. economy is in itself remarkable; it remains the largest economy in the world with one of the highest growth rates among the OECD countries. In 2015, U.S. Gross Domestic Product was $17,937.8 billion, based on the Bureau of Economic Analysis. The 2015 U.S. population was 322,762,018 with per capita income of $54,353. The U.S. economy is also remarkably dynamic, with a leading global position in software, biotechnology, pharmaceuticals, and aerospace, among others. It also benefits from high levels of innovation and entrepreneurship.

A Dynamic Innovation System

The explanation for the high levels of innovation and commercialization lies in the government's large and sustained investments in research—both basic and applied, reinforced by even larger research investments by the private sector. Moreover, the results of these investments are then carried forward with a supportive national innovation system which benefits from entrepreneurial universities that develop new ideas but also have a culture that supports their exploitation by their faculty and students. In turn, these innovative entrepreneurs are able to obtain early stage funding from a variety of sources in order to take their ideas to the market. The markets in turn are both competitive and largely open to the emergence of new, sometimes disruptive, technologies. The supportive policy framework, e.g. bankruptcy laws, and the willingness to accept new technologies, in addition to the presence of venture funding and experienced management sometimes enable these new firms to obtain significant global scale.

In short, despite ongoing challenges, the innovation system of the United States remains the most robust system in the world. Its strengths rely heavily on its research universities, a strong and effective intellectual property regime, multiple mission-oriented research agencies, deep financial markets, and positive framework conditions with regard to labor, bankruptcy, and tax laws. In combination, these institutions and policies continue to produce innovations that address global challenges in health, energy, security, and the environment.

Cluster Development

Smart specialization, per se, is not a focus of current U.S. policy making. It is a Commission initiative which as of yet has not been emulated in the United States. As described in the main body of the report, the Obama Administration has launched a major initiative modeled loosely on the German Fraunhofer Institutes to create clusters based on cooperative research centers with centralized facilities for new manufacturing technologies, such as wideband semiconductors, advanced metal alloys, smart textiles, and digital manufacturing. Much of the focus on cluster development in the United States is carried out at the state, and even the regional level. For example, a major cluster of nanotechnology in the Albany New York region (described in the text) has been successfully developed over a 15 year period with almost no federal support, yet it is now a globally recognized center of nano-research and semiconductor manufacturing.

International Cooperation

The United States plays a central role in global science through the quality and quantity of its research output, which remains disproportionately large in terms of top quality publications. The U.S. is also sought after as a partner, in some cases, as a result of its exceptional research facilities at national laboratories and leading universities. In the case of U.S.-European cooperation, it is important to underscore that much international cooperation occurs organically, often through the cooperation of scientists from U.S. universities and laboratories that collaborate closely with European counterparts. Indeed, there has been substantial growth in international research collaboration, as evidenced by the growth in jointly-authored publications. As described in the text, the United States and the European Union and its member states cooperate on a broad range of topics of mutual interest, such as electric cars, renewable energies, infectious disease, and national security. At the same time, international cooperation also faces structural challenges involving competing national priorities and capabilities, balancing contributions, and the need to ensure mutually beneficial results.

Structural Challenges

Notwithstanding its many strengths, the U.S. innovation system is not without its challenges. For example, the U.S. system is suffering from sustained declines in support for public universities and in funding for the national R&D effort, however, the downturn in R&D funding appears to be coming to an end as a result of recent budget agreements. Ongoing structural problems include the political blockage on immigration with its adverse implications for the talent pool, a limited understanding in policy circles of the strengths and nature of global competition, and a tendency for ideology to triumph over experience in the areas where government investment in future technology is required. At the same time, there are substantial policy efforts underway to address weaknesses in areas such as manufacturing and vocational training. The strengths, weaknesses, and current trends in the U.S. innovation system are described in the body of the report. Needless to say, the 2016 elections will have a major impact on both policy formulation and the level of support for the existing innovation system.

Conclusion

In sum, the United States has a long and successful history of meeting structural challenges over time, with the caveat that the challenges need to be recognized as such by policymakers and key constituencies. As discussed throughout this report, a major problem is the level of complacency that characterizes policy discussions on the U.S. position in the world. While eroding, this attitude is nonetheless a major impediment to needed investments in infrastructure, education, and research, as well as in the institutions and programs needed to capitalize on them. Indeed, the tradeoff between the focus on reducing government expenditure and debt versus investments in future knowledge and wealth generating capability remains to be resolved, even as there is growing recognition of the need to address global challenges in health, energy, the environment, and security. Perhaps the major challenge in the U.S. is to restore a sense of common purpose and constructive compromise in order to make the government a more effective tool in the service of current and future generations.

1. Overview of the R&I system

1.1 Introduction

The United States of America continues to have the largest economy in the world. In 2015, U.S. Gross Domestic Product was $17,937.8 billion, based on the Bureau of Economic Analysis.[1] The 2015 U.S. population was 322,762,018[2] with per capita income of $54,353.[3]

Unemployment continued a long-term decline, reaching 4.7% in May of 2016. This reflects a remarkable sustained economic expansion. The Gross Domestic Product (GDP) in the United States expanded 2 percent in the first quarter of 2016 over the same quarter of the previous year. GDP Annual Growth Rate in the United States averaged 3.21 percent from 1948 until 2016, reaching an all-time high of 13.40 percent in the fourth quarter of 1950 and a record low of -4.10 percent in the second quarter of 2009.

While the United States remains the world's largest economy, in the last two decades, like in the case of many other developed nations, its growth rates have been decreasing. If in the 50's and 60's the average growth rate was above 4 percent, in the 70's and 80's it dropped to around 3 percent. In the last ten years, the average rate has been below 2 percent and since the second quarter of 2000 has never reached the 5 percent level. Nonetheless, the U.S. economy has continued to grow, in contrast to many of the other developed economies. For example, over the last five years the U.S. economy has grown steadily, generating growth of 2.2% in 2012, 1.5% in 2013, and 2.4% in 2014.

The U.S. R&D/gross domestic product (GDP) ratio (or R&D intensity) was just over 2.8% in 2011 and has fluctuated between 2.6% and 2.9% during that decade, largely reflecting changes in business R&D spending. International comparisons are often problematic. For example, in 2011, the United States ranked 10th in R&D intensity—surpassed by Israel, South Korea, Finland, Japan, Sweden, Denmark, Taiwan, Germany, and Switzerland. However, all of these economies performed much less R&D annually than the United States. Moreover, some individual U.S. states, such as California, Massachusetts, New York, Maryland, and Washington, have accommodations of high private and public R&D, outstanding universities and research institutes, and effective developmental institutions that compare very favorably with similarly-sized countries in Europe.

Research policy benefits from the generally favorable view of the role of the federal government's role in funding investments in science and engineering. Research that addresses grand challenges is exemplified by ongoing investments in health, clean energy, and national security. Innovation policy has seen a major new initiative in advanced manufacturing, along with continued support for regional innovation clusters. Support for innovation policy as distinct from science is more problematic, although traditionally there is some discrepancy between objections in principle to government support for new technologies and actual practice.

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[1] Bureau of Economic Analysis. (Accessed February 2016). Gross Domestic Product: First Quarter 2016 (Advance Estimate). Retrieved from http://www.bea.gov/newsreleases/national/gdp/gdpnewsrelease.htm

[2] Census Bureau. (Accessed February 2016). Census Bureau Projects U.S. and World Populations on New Year's Day. Retrieved from https://www.census.gov/newsroom/press-releases/2015/cb15-tps113.html

[3] OECD. (Accessed February 2016). Gross domestic product (GDP) (indicator). doi: 10.1787/dc2f7aec-en

Figure 1 United Stated Indicators (2012 – 2014)[4]

Indicator	2012	2013	2014	EU average
GDP per capita	$51,368	$52,592	$54,353	27,300 EUR
GDP growth rate	2.2%	1.5%	2.4%	1.3%
Budget deficit as % of public budget	6.73%	4.08%	2.79%	86.8%
Government debt as % of GDP	100.83%	101.17%	102.98%	-2.9%
Unemployment rate as percentage of the labour force	8.1%	7.4%	6.2%	10.2%
GERD in $B	419.529	432.583	N/A	N/A
GERD as % of the GDP	2.699	2.742	N/A	N/A
GERD ($ per capita)	$1336	$1367	N/A	

Sources: Compiled from Bureau of Economic Analysis. (Accessed February 2016). Gross Domestic Product: First Quarter 2016 (Advance Estimate). Retrieved from http://www.bea.gov/newsreleases/national/gdp/gdpnewsrelease.htm
Census Bureau. (Accessed February 2016). Census Bureau Projects U.S. and World Populations on New Year's Day. Retrieved from https://www.census.gov/newsroom/press-releases/2015/cb15-tps113.html
OECD. (Accessed February 2016).

Notwithstanding the widely recognized contributions of the U.S. university system to innovation, economic growth, and national competitiveness, universities are confronting a variety of challenges with regard to revenue streams, changes in organization, costs of tuition, and shifting relations between research universities, government, and industry. They are also facing more competition from their counterparts overseas. However, for many years U.S. institutions have been able to attract outstanding students and scholars from around the globe who have contributed substantially to our research and innovative capacity,[5] and continue to do so today.

Competition for high-quality human capital has become more intense. The United States remains "the destination of choice for the largest number of internationally mobile students worldwide."[6] The absolute number of foreign students enrolled in the U.S. rose from 475,000 in 2000 to 784,000 in 2013. From an international perspective, the U.S. is nonetheless losing market share. Following the 2001 attacks, it became much more difficult for foreign students to enter the United States. Over the last decade, efforts by other countries to attract more foreign students have proved successful. The U.S. share of internationally mobile students fell from 25% in 2000 to 19% in 2013, with substantial shares now held by the United Kingdom, Australia, France, and Germany.

The scale of the U.S. research enterprise and the number and quality of its research universities (some 250) makes the U.S. a valued partner for scientific cooperation. Reflecting the many common interests and competencies, the U.S. has diverse and well-established scientific agreements with the EU and its member states. Formal science and technology cooperative agreements have been instituted between the US and Europe at

[5] National Research Council. (2012). Research Universities and the Future of America.
[6] National Science Board. (2016). Science and Engineering Indicators 2016.

the EU and individual country level and there also are networks that promote US-European scientific cooperation, science and technology presence within diplomatic offices, academic exchange programs, and cooperative actions of individual organizations and researchers.

Despite trends that threaten the long-term vitality of the American research enterprise, the scope and scale of U.S. investment in research, development, and innovation remains exceptional. Moreover, this effort generates its own momentum, which is accentuated through the multiple measures that have been adopted to encourage greater exploitation of research. These include programs such as SBIR (Small Business Innovation Research), the NNMI (National Network of Manufacturing Innovation) initiative, the I-Corp program, and new efforts in road mapping manufacturing, which all speak to the continued vitality of the American innovation system. Its underpinnings in terms of policy framework, R&D investments, and the strength of the universities are reviewed below, as are the important new initiatives mentioned above.

The innovation system of the United States remains the most robust system in the world. Its strengths rely heavily on its university systems, multiple mission-oriented research agencies, deep financial markets, and positive framework conditions with regard to labor, bankruptcy, and tax laws. The strengths of its institutions, notably its innovation agencies and research universities, combined with the scope and scale of the technology investments, the size of the domestic market, and the impact of innovative procurement all give the United States unique advantages in fostering innovation. Recently the U.S. government has also shown an ability to undertake institutional innovation, which arguably is a critical element in a nation's ability to sustain innovation. Institutions such as the Advanced Research Projects - Energy (ARPA-E), the new National Network of Manufacturing Institutes (NNMI), and state-based initiatives such as the College of Nanoscale Science and Engineering (CNSE) in Albany underscore the importance of new structures and the new constituencies needed to exploit the opportunities of emerging technologies.

These long-standing advantages are complimented by an ability to learn, both from previous U.S. experience and from the practices of others. To some extent, the decades following the Reagan Administration saw an erosion of understanding of the prominent role and catalytic impact of federal investments in the innovation system.[7] The reaffirmation of this role by the Obama Administration has proved powerful "on the ground," with Federal investments in manufacturing and renewable energy, e.g. solar and wind power, now generating substantial power, as well as creating influential constituencies across partisan boundaries. At the same time, the current administration is exceptional in that it has consciously sought to learn from best practices abroad. For example, it has drawn important lessons from the study of the role of the Fraunhofer Manufacturing Institutes in the German economy, or best practice in vocational training from Switzerland as well as Germany.[8] This "learning from others" is relatively unusual in the context of U.S. policymaking, particularly in regard to innovation.

While the Obama Administration has seen major successes, there are major clouds on the horizon which may threaten recent advances in U.S. innovation policy. A major challenge is the upcoming election in November of 2016. As some Washington commentators have suggested, there are two risks to current innovation initiatives. The first is that the Republicans win. The second is that the Democrats win.[9] The more

[7] This entrepreneurial role of the federal government has been underscored by well-known scholars (Ruttan, 2001, 2006) and the state's entrepreneurial role as an investor willing to take risks has been recently described by Mazzucato (2013). See below.

[8] 21st Century Manufacturing: The Role of the Manufacturing Extension Partnership Program. (2013). Ed. C. Wessner. National Research Council. National Academies Press.

[9] While the lack of consensus is real, the NNMI was authorized through the Revitalized American Manufacturing and Innovation Act (RAMI) in a highly unusual example of bipartisan cooperation. The Act

serious point is that, like many countries, the U.S. suffers from a lack of policy continuity, with the notable exception of military security initiatives[10]. The United States often finds it hard to provide the sustained political will and substantial funding necessary for successful civilian innovation initiatives.

In part, this lack of continuity reflects the lack of political consensus on the role of the government in developing the nation's economy. This is a debate that reaches back to the origins of the Republic.[11] This non-interventionist perspective (again, with an exception for national security) is often held by more orthodox economists and commentators, and is widely represented in policy circles. These beliefs seem to reflect, literally, a lack of knowledge about the scale and impact of government investments in new technologies and ongoing support in established industries. Consequently, the implications of this viewpoint contribute greatly to the dominant narrative in the U.S., which tends to leave out the role of government in major technological developments as diverse as nuclear power, satellites, the Internet, health, and energy, e.g. the shale gas revolution, as well as solar and wind[12]. This lack of awareness of the historical contributions of the government in creating new business opportunities is an enduring problem in building support for government investments in R&D.

The manufacturing initiative is designed to directly address a key challenge facing the U.S. economy; mainly our ability to manufacture at scale the new products developed through the RD&I system. Numerous new high-tech products, ranging from iPhones to LCDs to lithium ion batteries to advanced machine tools, were developed within the United States but are now largely produced overseas, creating a significant impact on future development paths[13]. The manufacturing initiative (described below) has been created with a broad regional base. This reflects the interest, expertise, and historical clustering of capabilities; the geographical distribution of the institutes may also act to enhance the political support for the effort.

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passed the Congress with widespread bipartisan support and was signed into law on September 16, 2014. This is very promising for ongoing policy continuity. The requirement for private sector matching funds, and the substantial financial contributions made by the business communities to the centers, suggests a substantial and potentially enduring constituency for the Institutes.

[10] A Republican Administration is likely to be opposed on the grounds of ideology and a Democratic Administration might want to mark its arrival by establishing new programs.

[11] "... since its founding fathers, the United States has always been torn between two traditions, the activist policies of Alexander Hamilton (1755 - 1804) and Thomas Jefferson's (1743 - 1826) maxim that 'the government that governs least, governs best'. With time and usual American pragmatism, this rivalry has been resolved by putting the Jeffersonians in charge of the rhetoric and the Hamiltonians in charge of policy." -- Erik Reinert (2007, 23) cited in Mazzucato, M. (2013). The Entrepreneurial State. Anthem Press.

[12] This view of the role of government in innovation and technology development in employment has been articulated by the program the author directed and edited at the National Academies of Sciences over the last two decades. See for example Conflict and Cooperation in High Technology Trade. 1996. National Academies Press.

See also The Advanced Technology Program: Challenges and Opportunities. 1999, National Academies Press.and The Advanced Technology Program: Assessing Outcomes (2001), especially the introduction. More recently, see Rising to the Challenge: U.S. Innovation Policy for the Global Economy. 2012. Ed. C. Wessner. National Research Council. National Academies Press.

Mazzucato (cited above) makes a refreshing and well-argued case for the importance of what she described as the "Entrepreneurial State". This view was articulated more completely, not only in the National Academy Study cited above, but also notably by Vernon Ruttan in his 2001 work and his 2006 study Is War Necessary for Economic Growth. Despite this wealth of evidence, the dominant narrative often heavily discounts or dismisses entirely the role of the federal government in providing support. See for example the discussion on the origins of the shale gas revolution in the Washington Post. See: Shellenberger, M & Nordhaus, T. (Dec. 16, 2011). "A boom in shale gas? Credit the feds". The Washington Post. Web.

[13] This challenge is documented in a major MIT study *Productivity in the Innovation Economy.* 2013. Suzanne Berger, ed.

Another major cloud on the future of the U.S. system is the declining support for public university systems, which have seen a substantial drop in state support for students on a per capita basis[14]. This is joined by the ongoing challenges with respect to the level of U.S. R&D investment (although that has recently improved). Another major challenge to the U.S. system is the impact of mercantilist trade policies on U.S. manufacturing employment. While their impact is beyond the purview of this report, it can act to undermine support for investments in new technologies and the willingness of U.S. labor to adapt to make the necessary transitions. Another troubling trend in the U.S. system has been the decline in entrepreneurship activity, particularly by younger cohorts. Recently, there has been resurgence in entrepreneurship activity, which, while reassuring, has not yet returned to pre-Great Recession levels. The causes of the decline are complex and not well understood. Some observers argue that the rising levels of student debt may be contributing to the decline in entrepreneurship[15].

The overarching challenge for the U.S. system is the complacency that characterizes much of the political leadership with regard to investments in infrastructure of all types, e.g. research facilities, as well as transport, water, and energy. This extends to funding for applied research and technology development and commercialization programs, as well as the public-private partnerships needed to capitalize on the opportunities apparent in new technologies. In that sense, the election may hold the prospect of shifts in the political landscape that would enable greater cooperation in Washington and more focus on the challenges facing the country.

1.2 National R&I strategy

The Obama Administration has taken the most comprehensive review of the U.S. innovation system in recent memory. Reflecting this systematic approach, it has created several "Innovation Reports;" the most recent published in November 2015.[16]. This last report is by far the most comprehensive, while the President's agenda has been both broader and more iterative than the reports themselves. The current report calls for investment in "the building blocks of innovation", that is, investments in research, STEM education, physical infrastructure, and next-generation digital infrastructure. The program also calls for federal investments to empower private sector innovators by addressing market failures that hinder innovation and by ensuring framework conditions supportive of innovation and entrepreneurship. This includes broadening and extending the R&D tax credit, commercializing federally-funded research, and supporting the development of regional innovation ecosystems. The program also seeks to encourage more Americans to be innovators through incentive prizes, supporting "Making", implementing crowdsourcing, and supporting STEM education. Emphasis is also placed on investing in manufacturing and new promising technologies. In addition, the program also calls for investment in targeted efforts to address "grand challenges" – precision medicine, the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) initiative, advanced vehicles, smart cities, clean energy, as well as more innovative and responsive government.[17]

The current agenda is both comprehensive and ambitious. It included a series of interlocking initiatives that require significant investment and, on occasion, major policy change. The President has pursued a broad-ranging program that includes:[18]

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[14] National Science Board. (2012). *Science and Engineering Indicators 2012*. See section 6.1.

[15] See for example statements by Mitch Daniels, former Head of OMB (Office of Management and Budget) Ex-governor of Indiana, and current President of Purdue University.

[16] Included in Annex. National Economic Council and Office of Science & Technology Policy. (October, 2015.) *A Strategy for American Innovation.* (Updated version).

[17] See Annex.

[18] National Economic Council and Office of Science & Technology Policy. (February, 2011). *A Strategy for American Innovation.*

- Investing more in R&D, including both in fundamental research and in highly applied fields such as renewable energy where relatively new organizations such as ARPA-E are designed to push new innovations towards the market;
- The Administration launched a number of initiatives to grow a skilled work force, with a particular emphasis on STEM education and middle skills or vocational training. The latter has been much neglected in the U.S.
- Attracting a skilled workforce involves immigration reform, where progress on improving the visa system for skilled workers has been modest[19]

1.3 R&I Policy initiatives, monitoring, evaluations, consultations, foresight excercises

The U.S. system is characterized by multiple new initiatives, a strong monitoring and evaluation culture, and, more recently, extensive consultations with relevant stakeholders, including attention to their input. Evaluations vary in scale, scope, and rigor with internal government assessments by the General Accounting Office and the Congressional Research Service. The National Academies of Sciences is often a source of high-quality outside analysis. Major think tanks often provide thoughtful and critical assessments of government programs and policy options.

An important source of evaluation in the process of program formulation involves consultations with relevant constituencies. A good example of this is the recent development of the National Network of Manufacturing Institutes (see section 4.3). The development of the program involved extensive outreach to industry and academia, as well as state officials in an effort to understand the need for manufacturing centers and to generate support for the initiative. Substantively, similar efforts were made to identify the most promising sectors for cooperative research and facilities. These included topics such as wideband semiconductors, advanced metal alloys, smart textiles, and digital manufacturing. This pre-commitment consultation ensured that the government initiative would have address a promising technological area while also benefitting from financial and policy support from industry, universities, and regional governments. The National Institutes of Standards and Technology has just recently commissioned an arm's length study by Deloitte to assess the effectiveness to date of the initiative. This intensive consultation before committing resources, the reliance on substantial cost-share, and the relatively rapid commissioning of an outside assessment represent exceptional best practice.

The SBIR program, which provides funding for early stage firms (as described below), was the subject of a large-scale, research intensive evaluation by the National Academies of Sciences[20]. The use of the National Academies ensured an arm's length evaluation, as well as the prompt public release of the analysis. The scale of the study, with its extensive surveys and field research involving interviews with companies, program directors, congressional staff, technical monitors, and senior officials, all contributed to an exceptionally thorough understanding of the operation of the program, its role in the U.S. innovation system, and its challenges and achievements. A major source of the success of the evaluation was both the expertise of the National Academies, particularly the expert volunteers it was able to draw on, and its reputation for impartial, evidence-based analysis[21].

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[19] See section on immigration reform.
These challenges are broadly comparable to the Horizon 2020 societal grand challenges.
[20] For the summary report of the extensive study, see Wessner, C. W. Ed. (2008). *An Assessment of the SBIR Program*. National Research Council. National Academies Press. The individual reports are cited below.
[21] National Research Council, *An Assessment of the Small Business Innovation Research Program: Project Methodology*, Washington, DC: The National Academies Press, 2004; National Research Council, *SBIR—Program Diversity and Assessment Challenges: Report of a Symposium*, Charles W.

As noted below, foresight is not a formal ongoing component of the U.S. system, but that may be beginning to change, as reflected in recent initiatives. See 1.4.1 below.

1.4 Structure of the national research and innovation system and its governance

1.4.1 Main features of the R&I system

Policy Initiatives

Obama Administration policy initiatives that required Congressional approval and/or funding generally have not been implemented, at least until the December 2015 agreement described below (Section 1.6). The most notable exception to this relative paralysis has been the new manufacturing initiatives.

Monitoring

Monitoring the U.S. innovation primarily occurs at two levels. The Executive Branch monitors expenditure and impact through self-evaluation, i.e. at the department or agency level. The Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB) monitor program organization and objectives, budgets, and outputs for the president, and to oversee agency activities. A major source of monitoring occurs at the Congressional level where departments and agencies are required to report to the relevant Congressional oversight committees.

Evaluations

Evaluations are conducted on an ad-hoc basis by the General Accountability Office, the Congressional Research Service (CRS), and private organizations such as the National Academies of Science, Engineering, and Medicine.

Consultations

Consultations have been a hallmark of this Administration's activities, with extensive outreach to universities, the private sector, and other stakeholders on new initiatives in STEM education, wireless technologies in spectrum, and clean energy development. The President's Council of Advisors on Science and Technology (PCAST), the National Science Board, and the National Defense Science Board. These are some of the best known and most influential consultative groups among many advisory committees.

Wessner, ed., Washington, DC: The National Academies Press, 2004; National Research Council, *SBIR and the Phase III Challenge of Commercialization: Report of a Symposium*, Charles W. Wessner, ed., Washington, DC: The National Academies Press, 2007; National Research Council, *An Assessment of the SBIR Program at the National Science Foundation*, Charles W. Wessner, ed., Washington, DC: The National Academies Press, 2007; National Research Council, *An Assessment of the SBIR Program at the Department of Defense*, Charles W. Wessner, ed., Washington, DC: The National Academies Press, 2009; National Research Council, *An Assessment of the SBIR Program at the Department of Energy*, Charles W. Wessner, ed., Washington, DC: The National Academies Press, 2008; National Research Council, *An Assessment of the SBIR Program*, Charles W. Wessner, ed., Washington, DC: The National Academies Press, 2008; National Research Council, *An Assessment of the SBIR Program at the National Aeronautics and Space Administration*, Charles W. Wessner, ed., Washington, DC: The National Academies Press, 2009; National Research Council, *An Assessment of the SBIR Program at the National Institutes of Health*, Charles W. Wessner, ed., Washington, DC: The National Academies Press, 2009; National Research Council, *Venture Funding and the NIH SBIR Program*, Charles W. Wessner, ed., Washington, DC: The National Academies Press, 2009; and National Research Council, *Revisiting the Department of Defense SBIR Fast Track Initiative*, Charles W. Wessner, ed., Washington, DC: The National Academies Press, 2009.

An American Foresight/Coordination Initiative: The Road Map Exercise for Semiconductors

There are cases in which coordination became essential and resulted in initiatives by industry to cooperate with government, universities, and the supply chain to develop what became known as the "Semiconductor Roadmap". Technology roadmaps, which are now widespread, are strategic tools for planning resource allocation and identifying research needs and challenges in evolving technologies over a relatively long time horizon. The most successful roadmaps are developed and refined by collaborating with stakeholding private, public and academic organizations that have a role in carrying out tasks identified during the roadmapping process. Roadmapping and technology forecasting were adopted by U.S. military planners during and after World War II in areas such as atomic power, missile defense, and aviation, and spread to the semiconductor industry, with individual U.S. companies beginning to adopt the practice internally by the mid-1970s. In the U.S. semiconductor industry, roadmaps have featured technology targets to be reached by specific dates based on parameters such as process feature size and device capability and density. The annex provides a review of the role of roadmapping in the semiconductor industry and its subsequent use by Sematech, the U.S. semiconductor manufacturing consortium.

A New Foresight Initiative in Manufacturing[22]

The June 2011 PCAST report to President Obama on "Ensuring American Leadership in Advanced Manufacturing" identified gaps in the U.S. innovation pipeline between basic research and manufacturing-readiness[23]. The Council made a key recommendation to invest in pre-competitive translational research and created the Advanced Manufacturing Partnership (AMP), which led to the establishment of Manufacturing Innovation Institute (MII), announced by President Obama in March 2012.

The establishment of the AMP and the National Network for Manufacturing Innovation (NNMI) demonstrates the national strides in revitalizing advanced manufacturing. One of the priorities from the PCAST October 2014 AMP 2.0 report was to create an advisory consortium to organize public and private priorities for the development of emergent advanced manufacturing technologies. The advisory body will focus on fostering national communication, creating a sustainable mechanism for discovering next-generation opportunities, and identifying priorities for manufacturing that can shape government and private sector investment in technology development. MForesight is the direct outcome of this recommendation.

MForesight is designed to serve as a "think-and-do tank" to forecast next generation technologies that will lead to future U.S-based manufacturing. MForesight focuses on providing technology roadmaps (see the section on semiconductor technology roadmaps above) and reports to the broad manufacturing community regarding emerging technologies and opportunities for public-private investments in advanced manufacturing. MForesight also seeks to promote technology innovation to bridge the gap between science and U.S.-based manufacturing. MForesight's tasks include:

1. Convening national thought leaders to identify and prioritize nascent technologies;
2. Commissioning subject matter experts (from a pool of over 30,000) to prepare timely reports and technology roadmaps on emerging technologies for future investments by convening subject matter experts expeditiously;
3. Serving as a national network for identifying and sharing best practices in technology commercialization and workforce development;

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22 See MForesight. "About Us". Retrieved June 2016 from http://mforesight.org/about-us/. This section is drawn from that site.

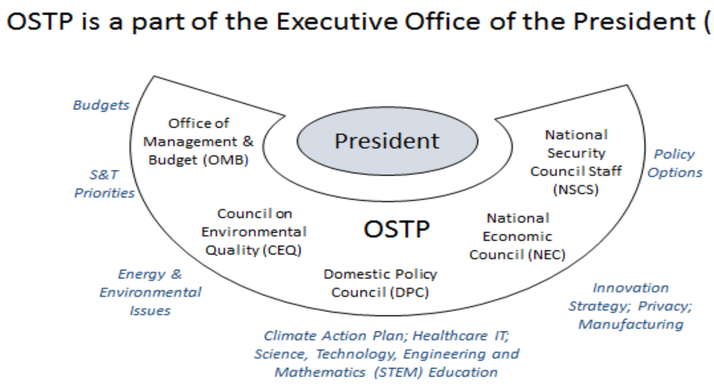
23 See section 4.3 in this report entitled, "The PCAST Anaylsis". The full report is at: PCAST Report to the President. (2011). *Report to the President on Ensuring American Leadership in Advanced Manufacturing.* Office of Science and Technology Policy.

4. Communicating findings and articulating technology opportunities in advanced manufacturing to broader manufacturing community including NIST-MEPs;
5. Promoting career opportunities in engineering and advanced manufacturing with emphasis on encouraging participation of diverse workforce; and
6. Articulating criteria & methods for evaluation and course correction regarding technology forecasting.

1.4.2 Governance

The U.S. innovation ecosystem is diverse, decentralized, and dynamic. It is much more decentralized than most innovation systems, a point which is sometimes hard for outside observers to fully grasp. Policy is shaped both in a top-down and a bottom-up fashion, with large, mission-driven agencies determining their own agendas, often in close cooperation with responsible Congressional committees that provide funding and oversight. Additional oversight is provided by the Executive Branch through the White House Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB). The latter manages the budgetary process, subject to advocacy by the Agency as well as interventions—and ultimately funding—by the Congress. OSTP has multiple roles that include budgetary review, coordination of budgets in cross-cutting areas, and advice to the President on priorities and opportunities in research and innovation policy. Under the Obama Administration, the role of OSTP in innovation policy has expanded considerably.[24]

Figure 2: OSTP Organizational Chart[25]



OSTP has expanded considerably under the Obama Administration. Currently, OSTP has a 2016 budget of $5.6 million and 130 staff. 90 of these staff are technically-trained and on detail, i.e. secondment, from federal agencies or Intergovernmental Personal Act (IPA) assignments, e.g. university professors or industry representatives. In recent remarks, science advisor Holdren noted that the Administration recruited top S&T talent to advise the president, such as PCAST (President's Council of Advisors on Science and Technology). The Administration, somewhat exceptionally, has also recruited scientists and engineers to head federal departments, such as the Departments of Energy and Interior. Well-trained professional staff also head agencies such as the Environmental Protection Agency (EPA), the National Institutes of Health (NIH), the National Institutes of Science and Technology (NIST), the U.S. Geological Service (USGS) as well as NASA and NOAA (National Oceans and Atmospheric Administration).

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[24] The Director of OSTP, Dr. John Holdren, is also the President's Science Advisor, holding the rank of Assistant to the President, a rank his predecessor did not hold. This title, but more importantly the President's interest, has assured regular access for the Science Advisor to the President and active participation for OSTP in the policy process.
[25] Fall, Chris. Presentation at Georgetown University on, *inter alia*, the OSTP Structure. 2015, Oct 27.

Distributed Authority

The importance of the federal structure of a government is often overlooked when assessing U.S. policy. As a previous report observed, "The US is a federal system, with governmental powers not explicitly allocated to the national government reserved to the state and local governments. State governments also delegate powers to local governments. As a result, the US has a multi-level system of regional governance which includes 50 states; five equivalent legal territories; more than 900 metropolitan and micropolitan areas, more than 3000 counties, boroughs, and parishes; and more than 25000 cities and towns. Each state has a different governance structure for local entities. Some powers are shared between national, state and local governments, such as the power to tax." [26] This diversity of authority can and does complicate innovation initiatives. For example, the Department of Energy solar program reports that permits for home solar installation are subject to some 16,000 different municipal authorities across the nation, adding considerable complexity to efforts to accelerate adoption rates. At the same time, this diversity responsibility allows states and regional authorities to carry out independent innovation initiatives, often with considerable impact, as discussed in the New York Smart Specialisation initiative below.[27]

A Diffused but Effective System

The diffusion of power throughout state and local authorities, the diversity of practice across public and private research universities, the paramount role of mission agencies, and the pervasive, sometimes dominant influence of Congressional committees on mission priorities and resources collectively generate what might best be termed "constructive confusion" with respect to U.S. management of innovation policy and initiatives.

While often disorderly, this state of affairs is generally speaking positive—and in any case, it is the state of affairs. The dispersed authorities allow for rapid shifts in priorities, now enabling surges in R&D funding when the various parties agree. Furthermore, spaces are left for new agency initiatives, such as the "War on Cancer" or the new "Cancer Moonshot" and the "BRAIN Initiative," which are all intended to galvanize resources around a long-term goal. The broad range of participants often provides for multiple experiments and the exploration of new paths, while generating both redundancies and gaps in investment (though both are corrected over time). Despite some surface confusion, the collective effort normally provides broad and sustained support for research, development, innovation, and its commercialization: all hallmarks of the U.S. innovation system.

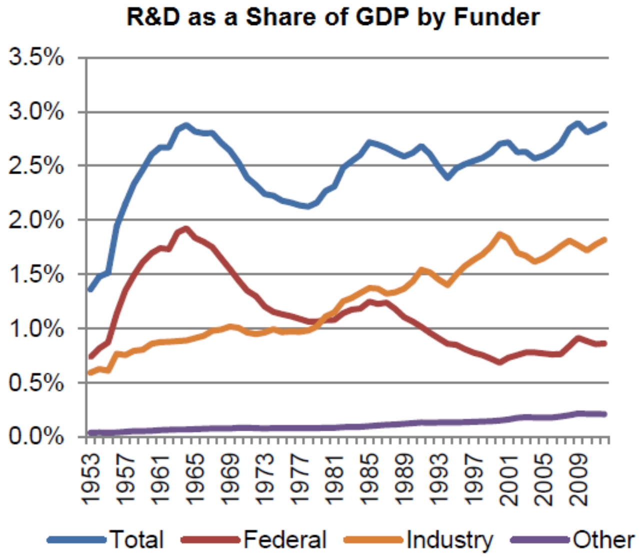
1.4.3 Research performers

As noted elsewhere, industry now accounts for the vast majority of American national research and development. This share has been growing for decades, reflecting a steady shift in allocation from two-thirds federally supported R&D to nearly two-thirds private R&D. Interestingly in this process, the relative shares of basic research, applied research, and development have all held relatively constant or grown as a share of the economy. The graph below indicates the current share of national R&D by funder. The allocation within these shares varies with industry share much more focused on development.

Figure 3: R&D as a Share of GDP by Funder

[26] Youtie, J. (2012). *ERAWATCH Country Reports 2011*. United States of America.

[27] Wessner, C. (2013). New York's Nanotechnology Model: Building the New York Innovation Economy. National Academies Press.



Source: National Science Foundation, *National Patterns of R&D Resources* survey series.

Performers of federal R&D

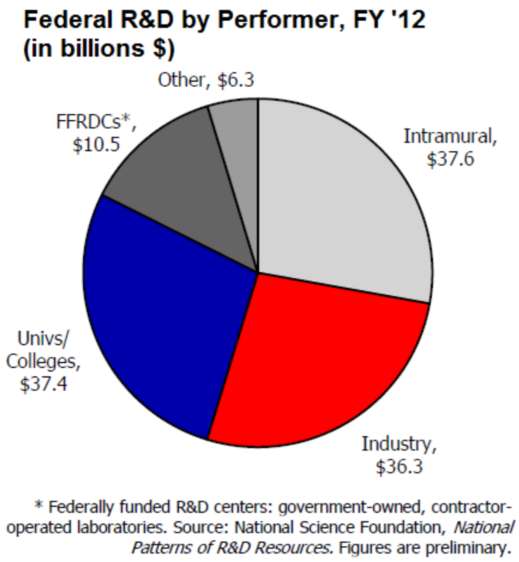
Federally funded R&D is conducted by a range of performers[28]. The figure below shows the distribution of research and development by performer (this figure excludes R&D plant). Federal R&D is shared among intramural researchers, industry, and universities with each accounting for about 29%. The National Laboratories, formally known as federally funded R&D centers, account for some 8%, with the remainder accounted primarily by non-profit research institutes. Department of Defense (DoD) funding tends to emphasize industrial contractors who undertake technology development for its major programs.

The Department of Defense also maintains an extensive intramural research enterprise, e.g. the Office of Naval Research. The scale of DoD research also enables it to play a major role as a university research funder, surpassed only by the National Institutes of Health (NIH) and the National Science Foundation (NSF). The NIH also maintains a significant intramural research capacity.

The scale of the NIH effort is worthy of note. The NIH is the largest source of funding for medical research in the world with over $30.9 billion annually (recently increased by $2 billion). More than 80% of the NIH's budget goes to more than 300,000 research personnel at over 2,500 universities and research institutions. The Institutes made $25,503,932,912 in externally funded awards in 2012. As noted, the intramural program is significant as well. The NIH is comprised of 27 Institutes and Centers, each with a specific research agenda, often focusing on particular diseases or body systems. Over 6,000 scientists work in NIH's own Intramural Research laboratories in Bethesda, Maryland. The impact of the NIH is difficult to overstate. It is a key foundation for the medical innovation sector in the United States, which employs 1 million Americans and provides information and opportunities for scientists and industry around the world.

[28] Houritan, M. (January 15, 2015). *Federal R&D Budget Trends: A Short Summary*. AAAS.

Figure 4 Federal R&D by Performer (2012)



The Department of Energy (DoE) spends the largest share of its funding through the National Labs, both for its civilian and defense science & technology applications. NASA's greatest expenditures are for R&D carried out by industry. The diversity of the performers and the communities they have developed represent a significant strength in the U.S. innovation system.

1.5 Quality of the Science Base

Publications

The United States retains its position as a top producer of science publications, and is a clear leader in frequently cited work.

Research produces new knowledge. S&E publications are one of the tangible measures of research activity that are broadly available for international comparison. The United States, the EU, and the rest of the developed world produce the majority of refereed S&E publications. However, similar to the trends for researchers and R&D spending, S&E research output in recent years has grown much more rapidly in China and other developing countries when compared with the output of the United States and other developed countries. China's global share of S&E publications tripled from 6% in 2003 to 18% in 2013. As a result, China's share is now comparable—in terms of the number of publications—to that of the United States. Research output has also grown rapidly in other developing countries, particularly Brazil and India.[29]

U.S. publications, however, continue to receive the largest absolute number of citations; when adjusted for the size of each country's research pool, it joins in this measure with Canada, Switzerland, the Nordic countries, and the United Kingdom in setting the bar for the production of influential research articles.[30]

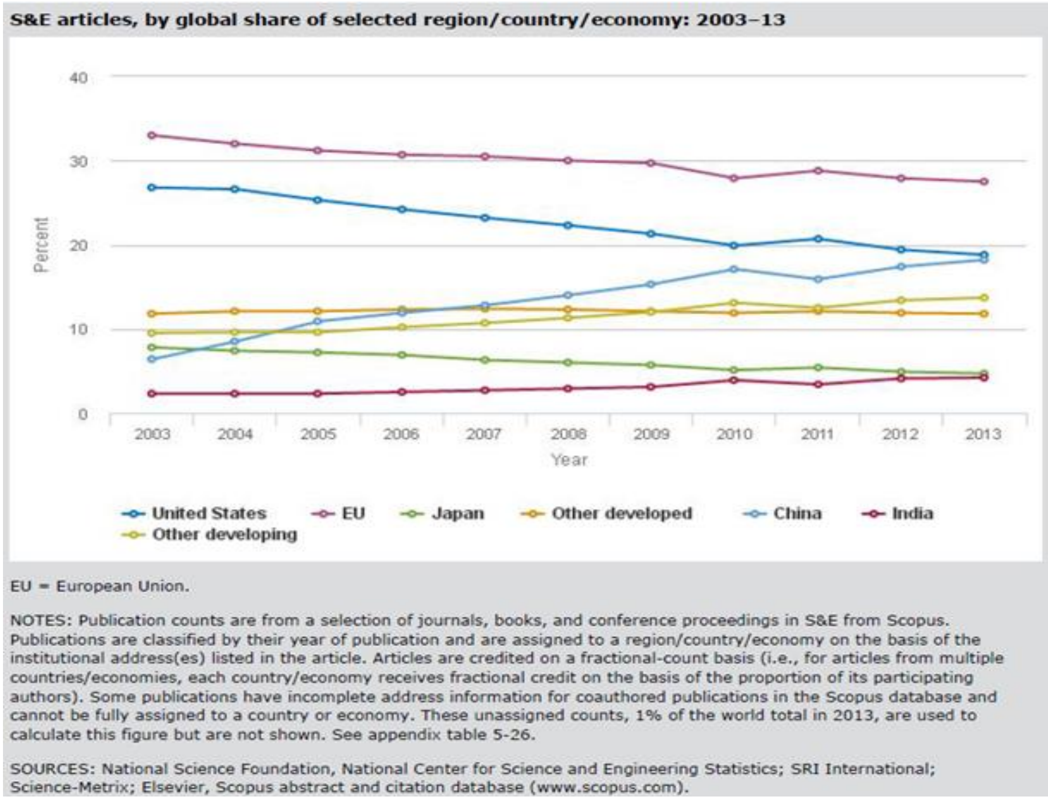
[29] National Science Board. (2016). *NSF Indicators, 2015.* Page 19.

[30] When researchers in one country cite the published work of researchers in another country, the resulting citation patterns are considered an indication of knowledge flows across regions. It is important to note, however, that these patterns are influenced by cultural, geographic, and language ties as well as perceived research quality. For example, researchers are more likely to cite work written in their native language. U.S. articles are disproportionately cited by Canadian and United Kingdom authors and vice-versa, whereas Chinese articles are less cited than would be expected based on the overall number.

One measure of the influence of a country or region's research is its share of the world's top 1% of cited articles compared to what would be expected based on the size of each country's pool of S&E publications. With this measure, if a country's share is exactly what would be expected based on size, the percentage is 1%. The U.S. percentage has held fairly steady at about twice the expected value (1.8%–1.9%), while the percentage of articles from the EU in the top 1% grew from 1.0% to 1.3% between 2001 and 2012. China's share of this top 1%, starting from a low base, almost doubled in the same period, from 0.4% to 0.8%.[31]

In short, while the number of publications continues to grow rapidly, the U.S. retains its leading position with significant variations by field, albeit in a quickly evolving market. While there are no grounds for complacency, it is equally true that the U.S. science advantage and its global contribution remain strong. What is much more problematic is the ability of the U.S. to convert its scientific progress into the large-scale production of new products and processes. The figure below illustrates the evolution of science and engineering articles by global share.

Figure 5 Global Share of S&E Articles (2003 – 2013)



Broadly speaking, the President's policies, as outlined in a speech by the director of the National Economic Council, included the following elements[32]:

- More federal investment in R&D
- Measures to Grow and Attract a Skilled Workforce
- Invest in Infrastructure for Innovation
- Renew the Manufacturing Base
- Invest in Clean Energy Innovation
- Reform the Patent System
- Encourage Entrepreneurship

[31] Ibid. Page 21.

[32] *A Strategy for American Innovation*. (February 2011). White House NEC, OSTP

The most fundamental change has been the recent reversal of the decline in the national R&D budgets from the 2009 highs. This shift is very promising, particularly if the current bipartisan agreement to increase R&D budgets can be sustained. Another major development is the rapid expansion of the administration's manufacturing initiatives. These industry-university-government partnerships are designed to capitalize on national R&D investments and, most importantly, anchor know-how and production of these new technologies within the U.S. economy. Workforce training has also received renewed attention after years of neglect, with substantial funding flowing to community colleges and unprecedented policy attention is being given to lessons derived from European models. A fourth area of promise is the recent increase in funding for agencies responsible for monitoring and understanding climate change. The growing use of new incentives for innovation, i.e. prizes, and new institutions such as ARPA-E are now joined with adjustments to the policy framework, i.e. making the R&D tax credit permanent. These initiatives underscore the diversity of mechanisms and incentives brought to bear by the multiple, highly-diverse contributors to the U.S. innovation ecosystem.

While these recent advances are positive, serious challenges remain, notably with regard to the continued strength of the U.S. university system. Financial support for public universities has declined by 20% over the last 10 years on a per-student basis[33]. Perversely, this funding decline has been accompanied by rising regulatory and administrative requirements and compounded by inadequate investments in university research infrastructure.

The New Manufacturing Initiative

The new National Network of Manufacturing Institutes (NNMI) represents a highly ambitious national effort to address a core national need, that is, to develop and refine new methods of manufacturing and then disseminate them broadly through a cooperative, regionally-based system. Each Institute is focused on a new and promising technology opportunity. These include additive manufacturing, digital manufacturing and design, lightweight metal alloys, next generation semiconductor manufacturing, advanced composites, integrated photonics, flexible electronics, next generation fibers and textiles, and "smart manufacturing." The effort to develop and build out the network has drawn on extensive analysis and public engagement in defining needs and design. At the same time, an intensely competitive process has been maintained. Progress has been remarkable, with seven major institutes in place, two forthcoming awards, and plans for six additional institutes scheduled for 2016. The goal is to create a national network of some 15 manufacturing hubs across the United States. At this writing (April 2016), the federal government has committed $600 million to 8 institutes. This has been matched by over $1.2 billion in non-federal investments from industry, academia, and state governments.

The most recently created Institute, created under the auspices of the Department of Defense with a consortium led by MIT, is focused on the production of fabrics and fibers with exceptional properties. The goal of the consortium is to cooperate in integrating fibers and yarns with integrated circuits, LEDs, solar cells, and other devices to create textiles and fabrics that see, hear, sense, communicate, store energy, monitor health, and change color as needed. The development of this network and its expansion across technologies and regions represents a major accomplishment for this Administration—one that must be sustained for this initiative to have a long-term impact.

New National Security Initiatives

The Administration's budget request for FY 2017 involves significant increases in R&D funding for defense. The budget proposal (in an election year) seeks $112.1 billion to

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[33] Mitchell, M. & Leachman, M. (13, May 2015). "Years of Cuts Threaten to Put College Out of Reach for More Students". *The Center on Budget and Policy Priorities.*

develop and procure equipment and technologies to advance capabilities in key technology areas, such as hypersonics, large-data analytics, advanced materials, and human-machine teaming. The request augments funding for its R&D accounts of $71.8 billion in 2017.

The budget also reflects the Department of Defense's (DoD) continuing efforts to connect with America's technology community. It includes $45 million for the Defense Innovation Unit-Experimental (DIUx)[34] intended to better connect DoD to the minority capacities of Silicon Valley, $40 million for its pilot program with In-Q-Tel (a government-funded venture fund). The latter is designed to leverage venture capital investors to help find innovative solutions for some of DoD's most challenging problems. There is $137 million to support its Manufacturing Innovation Institutes (reviewed below), including one focused on flexible hybrid electronics as well as the recently announced institute on Revolutionary Fibers and Textiles[35].

The R&D tax credit is now permanent

The U.S. R&D tax credit has suffered from decades of uncertainty and political squabbling. Since it was created in 1991, the tax credit has lapsed six times, most recently last year, and has been temporarily extended 17 times.[36] The short renewals and the uncertainty created by lack of consensus in Congress arguably reduce the impact of the tax credit, particularly for longer term investment plans. Industry groups, economists, and advocates for research have all pressed the Congress to make the tax credit permanent. Despite bipartisan backing for the concept, in the recent budget cutting environment, the cost of making the credit permanent was a major obstacle.

Currently, the credit costs the government some $7 billion in tax revenue annually. It is also among the most expensive to operate of all U.S. tax credits. Some estimates expect the decision to establish its permanence will cost the Treasury $100-150 billion over 10 years. Other analysts argue that these costs would be far outweighed by the benefits, suggesting that a permanent R&D tax credit will increase U.S. GDP by 0.16% annually and add some 36,000 jobs each year. In light of this decision, the National Association of Manufacturers in Washington D.C. stated that, "Short of comprehensive tax reform, this is one of the most significant steps Congress has taken in decades to improve our out-of-date tax code for businesses."[37]

Renewed Support for NASA's Planetary Exploration

NASA's science budget rose 6.6% for 2015. Planetary science received a major boost with an increase of 13.4%, reflecting a renewed interest in space exploration. Language in the bill directs the agency to apply $175 million towards a mission to Jupiter's moon, Europa, and also directs that the mission should have a lander component. The Congress also increased NASA's budget for the Low Cost Competitive Discovery Program by $189 million, which should allow the agency to accept finalists from the most recent competitions.

Renewed Funding for Climate Research

In a positive development, the two science agencies concerned with climate research received substantial increases. Perhaps more interesting from a policy perspective is the significant increase to NASA's Earth Science budget, which will now rise to $192 billion, an increase of 8.4% from 2015 levels. This represents a major shift in that funding from the Earth Science division nearly matched President Obama's budget request, indicating that the anti-climate science views of House Republicans disappeared in the final budget

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[34] Macdonald, N. Ed. (2016, February 15) *Federal Technology Watch (FTW).* Volume 14. Issue 7.
[35] *Ibid.*
[36] Mervis, J. (2015, December 18). *Updated: Budget agreement boosts U.S. science*. Retrieved May 10, 2016, from http://www.sciencemag.org/news/2015/12/updated-budget-agreement-boosts-us-science
[37] Ibid.

process.[38] In a similar vein, the National Oceanic and Atmospheric Administration (NOAA) received a 6% increase in funding, bringing its budget to $5.77 billion. This sum includes $462 million for the Office of Oceanic and Atmospheric Research.

The White House budget targets were not reached in this area, with $58 million for climate research authorized instead of the requested $89 million and $10 million for ocean acidification research rather than the Administration's request of $30 million. Nonetheless, these funding levels represent increases over the previous fiscal year and suggest a recognition that we need to learn more about these issues and their long-term impact on our Earth.

More broadly, the substantial increases for research at NOAA and in NASA's Earth Science budget are positive initiatives designed to bring new science-based information to our understanding of climate change.

New Mechanisms: Innovation Prizes

Under the Obama Administration, the Federal government has launched a sustained effort to use cash prizes to promote innovation. Perhaps the best known example is the Defense Advanced Research Project Agency's (DARPA) "Grand Challenge," launched in 2004. It offered a prize for $1 million for designing a driverless car that could be the first to successfully complete a desert course. The prize was not awarded, however, the challenge succeeded in generating a broad attention in the research community on the potential of driverless technology. A decade later, Google seems close to mastering this technology and most major automakers are working on driverless prototypes. Since then, DARPA has sponsored competitions involving humanoid robots and radio communications.[39]

Following the DARPA example, innovation prizes have expanded across the federal government, notably within NASA and the Department of Energy. Legislation in 2009 made it easier for federal agencies to launch their own competitions specific to their needs and missions, with awards ranging from a few thousand to several million dollars. Since 2010, more than 400 competitions have been held with over 100,000 participants.[40] Prizes offer a stimulating incentive for initiatives with a purpose, while limiting government expenditure to the prize itself, not the competition.

Proposed New Initiatives[41]

The National Science Foundation plans to expand its innovation efforts by funding new hubs of what it calls the Innovation Corps — a set of training programs and other initiatives to rapidly translate progress made in labs to the commercial world.

NSF is offering up to $8 million in cooperative agreement awards to researchers to form new I-Corps nodes, which are central hubs meant to "support regional needs for innovation education, infrastructure, and research" of I-Corps teams, according to a solicitation from the science and engineering research agency.[42] Typically these nodes are based around academic or nonprofit research entities and connect to form NSF's National Innovation Network — essentially a national innovation ecosystem for advancing practical and impactful research discoveries. Some of the first nodes were launched at Stanford University, Georgia Tech, and the University of Michigan. Each of

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[38] In 2015, language was inserted in the NSF appropriations limiting some of its climate-science research. That language disappeared this year for NSF, and importantly, none appeared in NASA's earth science budget. As one observer remarked, "Part of the story is language that isn't there." *Updated budget agreements AAAS*. (P. 12).

[39] Alden, E et al. *Keeping the Edge. U.S. Innovation*. (October 2015). Council on Foreign Relations.

[40] Ibid.

[41] Macdonald, N. Ed. (2016, February 15) *Federal Technology Watch (FTW)*. Volume 14. Issue 7

[42] National Science Foundation. Special Report – I-Corps Components. Retrieved from http://www.nsf.gov/news/special_reports/i-corps/components.jsp

those nodes is made up of other smaller I-Corps: sites that consist of actual teams performing the research.

The awarded nodes will be responsible for training at least five I-Corps teams per year and provide them an infrastructure for quickly moving their specialized ideas to market, but with long-term feasibility in mind.

Last August, NSF also announced a series of partnerships with federal agencies, including the National Security Agency and the departments of Defense and Homeland Security, and nonprofits to bolster innovation in particular areas of need such as intelligence, agriculture, and defense.

President Obama's 2017 Budget[43]

The President's budget requests reflect a broad range of objectives, ranging from stimulating the business environment, to meeting international commitments on climate, to protecting the U.S. water supply, and of course, national security. Leading major initiatives identified in the budget are described below.

Simplifying, Expanding the Research & Experimentation Tax Credit

As noted above, the Research & Experimentation Tax Credit is deemed an important federal incentive for private-sector research investments. The president signed legislation at the end of 2015 to make the credit permanent and expand the incentive for R&D investments by small businesses. The 2017 budget proposes to simplify and expand the tax credit for companies investing in innovation.

Addressing Agricultural Challenges through R&D

Recognizing the importance of S&T to meet challenges in agriculture, the budget plans investments in three major agricultural R&D areas: Agriculture and Food Research Initiative competitive research grants, Agricultural Research Service intramural research, and construction and renovation of key infrastructure investments based on the Department of Agriculture's facility modernization plan.

Supporting adoption of clean energy

As well as *Mission Innovation* funding, the FY 2017 budget seeks over $1.3 billion to accelerate adoption of clean energy sources such as solar, wind, and low-carbon fossil fuels, and energy-efficiency technologies.[44]

Leading global efforts to cut carbon pollution

In support of President Obama's Climate Action Plan, the budget provides 1.3 billion to progress the *Global Climate Change Initiative* (GCCI) through important multilateral and bilateral engagement with major and emerging economies. This includes $750 million in U.S. funding for the *Green Climate Fund* (GCF) to help developing countries leverage public and private financing to invest in reducing carbon pollution and strengthen resilience to climate change.

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[43] The U.S. budget cycle is for 1 October – 30 September. The 2017 budget will begin in October 2016.

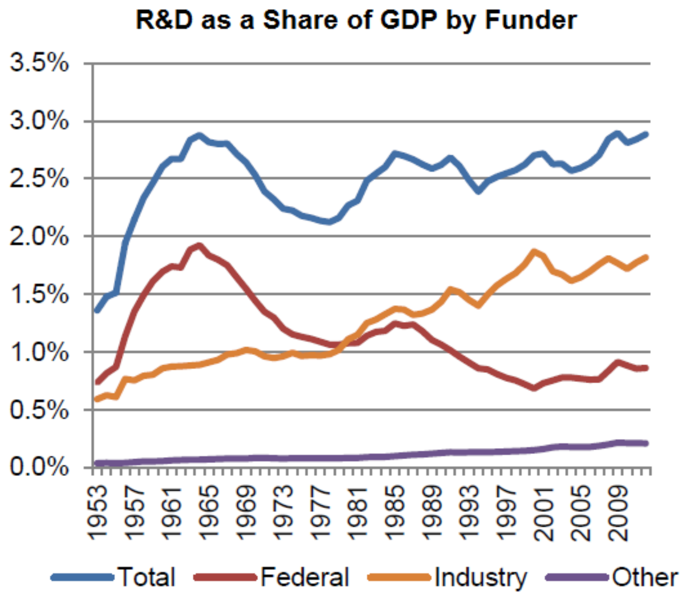
[44] See the Innovation Report in the Appendix. *AAAS Budget Agreement Boosts US Science*. Dec. 18, 2015.

2. Public and private funding of R&I and expenditure

Government plays a key role in the U.S. science and technology enterprise. The most immediate rationale for government investment is the need to address government missions in agriculture, environment, energy, health, infrastructure, and of course, national security. All of these public missions require interaction with and investment in science and technology.

Government investment is also driven by the societal benefits of R&D, which are normally considered greater than the private benefits from R&D investments. Private companies cannot normally capture the full benefits of investments in knowledge due to knowledge spillovers, often to competitors in the marketplace. The last decades have also seen growing recognition of the importance of government investment in research projects that entail considerable risk, with uncertain prospects for success and unclear future utility. To undertake these promising but high risk endeavors often requires a longer term of commitment of resources (and infrastructure) than the private sector can normally make.

Figure 6 R&D as a Share of GDP by Funder (1953 – 2009)

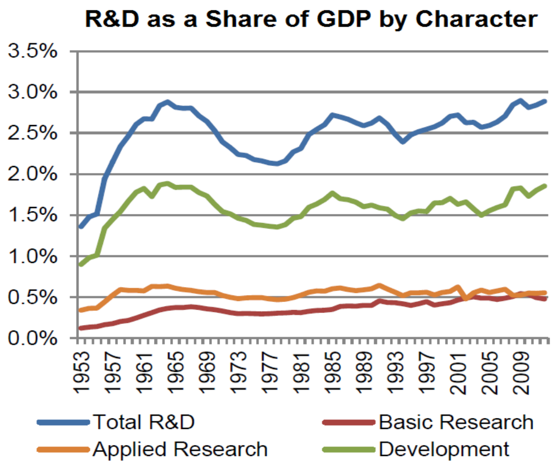


Source: National Science Foundation, *National Patterns of R&D Resources* survey series.

As noted above, R&D as a share of GDP is a metric used to describe "research intensity". It is a commonly used, yet somewhat limited, descriptor of a nation's overall R&D effort, particularly in its ability to prioritize public investment and induce private investment in science and technology. During the 1960s, driven by the space race and Cold War competition, federal R&D outlays peaked above 2.0%. As of FY 2014, the R&D budget had declined to an estimated 0.78% of GDP. Non-defense R&D has remained relatively constant as a share of GDP since the declines of the 1980s. Defense R&D has dropped sharply, which also means that development has dropped more quickly than basic and applied research relative to GDP.

The key development in the last decades is the change in shares of R&D expenditure between the public and private sector. As the federal share of R&D has declined, it has been more than offset by increased expenditures from industry as well as small additional contributions from universities, state governments, and foundations. Industry now counts for the great majority of American R&D, which has seen steady growth for decades. Interestingly, the character of expenditure has not changed substantially, even as government and industry funding shares have changed places. As the figure below shows, basic research, applied research, and development have all held relatively constant or grown as a share of the economy. This figure does not reflect the impact of the sequester and other reductions in R&D budgets after 2009.

Figure 7 R&D as a Share of GDP by Character (1953 – 2009)

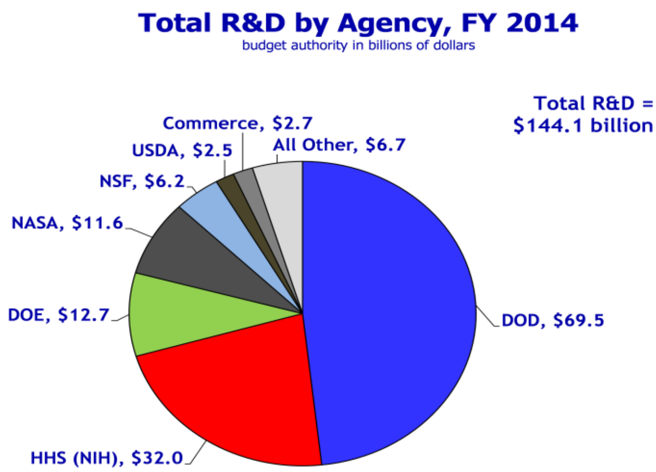


Source: National Science Foundation, *National Patterns of R&D Resources* series.

2.1 Relative Allocation of Defense and Non Defense R&D funding

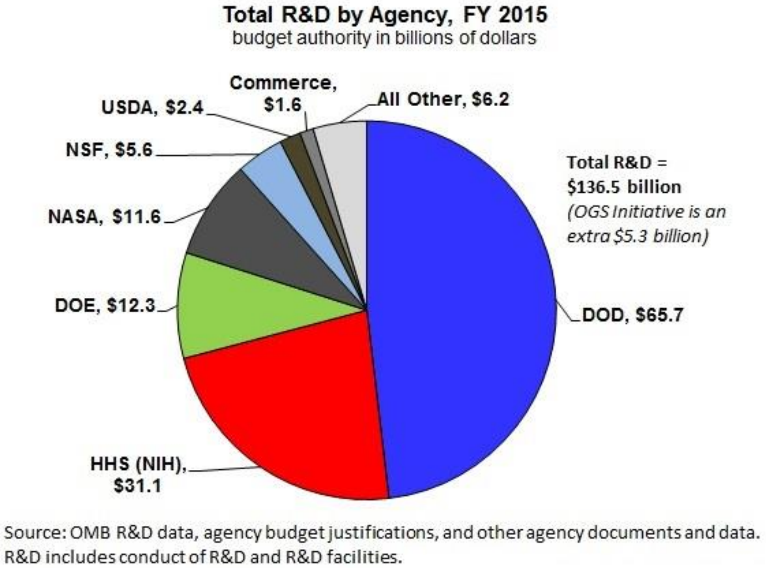
The national defense expenditure has typically accounted for greater than half of annual R&D expenditures. For example, in 2010 national defense was $86.8 billion, or 58.3% of the $149 billion total. In 2014, the national defense budget had dropped to $71 billion (out of a $136 billion total) and still represented 52% of R&D expenditure. The President's 2016 budget proposes a substantial 8.1% increase, or roughly $76.8 billion, but this would still be well below the $86.8 billion of 2010.

Figure 8 Total R&D Spending by Agency (2014)



Source: OMB R&D data, agency budget justifications, and other agency documents.
R&D includes conduct of R&D and R&D facilities.

Figure 9 Total R&D Spending by Agency (2014)



Interagency Allocations

The table above captures the relative allocation of R&D funding to the different agencies. The major recipient of course is the Department of Defense. However, funding for health is substantial and growing. Health R&D in 2015 is $31.4 billion, or 23% of the total. This represented a 1.1% increase, but still behind the pace of inflation.

The National Institutes of Health (NIH) is the recipient of almost all of these funds and is to receive substantial additional funds in 2016. As with defense, the substantial funding allocated to NIH reflects the sustained U.S. commitment to health research, which in itself is a global good. NIH funding is normally spread across multiple disease categories, with the National Cancer Institute (NCI) and the National Institutes of Allergy and Infectious Disease (NIAID) receiving the largest shares of the total. The strength of allocation to NCI and NIAID reflect current (2015) priorities. The NCI allocations underscore the Obama Administration's new "Moonshot Initiative" designed to add new resources and new impetus to the ongoing struggle with cancer. The funds for NIAID reflect ongoing awareness of health threats such as Ebola and the newly emerged Zika virus. In short, the U.S. is a key player in global health with R&D expenditures that substantially outpace peer countries.[45]

The health category also includes R&D programs of key agencies such as the Food and Drug Administration (FDA), Consumer Product Safety (CPS), and most notably, the Center for Disease Control and Prevention (CDCP), with the latter having a substantial global presence.

Funding for the Department of Energy (DoE) can be divided between science and basic research, nuclear research and energy. In this latter category, expenditure was $2.4 billion in FY 2015, with a proposed increase in 2016 to $3 billion. The energy category includes the Department of Energy's various energy programs, i.e. research on coal, gas, solar, wind, and geothermal. It also includes the Advanced Research Projects Agency-Energy known as ARPA-E, which is designed to develop new technology prototypes and then help push them to market.

[45] Reflecting the important contributions of the global scientific community as well as the global threat of infectious diseases, the U.S. has a wide variety of partnerships with countries around the world.

Allocation of Defense Spending

Indeed one of the challenges in assessing the overall U.S. R&D effort is to recognize the unique nature of the defense research enterprise. It is important to understand that the primary focus of DoD's R&D program is the defense mission, that is, the defense of the United States and its allies from threats to our security. It is also true that over time, defense innovation has made immense contributions both to U.S. competitiveness and to human welfare. For example, defense applications contributed enormously to the rapid development of semiconductors, which in turn have provided the building blocks for the entire ICT revolution. The Internet, arguably one of the key foundations of the modern economy, was developed by DARPA and the Office of Naval Research (ONR), in cooperation with CERN and others. ONR and DARPA also developed the global positioning system (GPS), again intended for military use, but GPS applications now permeate the economy through agriculture, mining, oil and gas exploration, aviation, and personal navigation. Despite these accomplishments, the military budget has a disproportionate focus on applied and especially developmental research.

It is important also to understand that defense R&D expenditure includes military research, development, test, and evaluation (RDT&E) programs. This funding includes a broad spectrum of activities, ranging from basic research to operational system development. In recent years, system development has accounted for 37% of the RDT&E total, often focused on upgrading systems that have already been fielded or are in full production. The bar chart below illustrates the striking allocation of R&D resources to the development side of defense spending. As a result of this allocation, one can argue that the US expenditures on research are overstated with regard to defense.[46]

2.2 Funding flows

Federal R&D turned modestly upward in 2014-2015

The federal budget authority for research development (including R&D plant) totaled an estimated $137.2 billion in FY 2015. This reflects an increase of $1.0 billion, or 0.7%, over FY 2014. The increased funding represents an important shift in the recent downward trend in U.S. R&D spending. For example, FY 2011 was down $4.6 billion and FY 2013 was down $11.3 billion. These cuts translated into a significant reduction from the 2009 high-water mark for U.S. R&D of $164.3 billion. This significantly larger sum resulted from the appropriation $145.6 billion plus a one-time $18.7 billion increase from the American Recovery and Reinvestment Act of 2009, that is, the stimulus package adopted by the federal government to help counter the 2008-2009 recession[47].

The successive years of decline in R&D funding have been a subject of concern for the U.S. scientific and business communities. Modest increases in FY 2014-15 of $3.7 billion and $1 billion respectively did not restore funding to previous levels. FY 2015 ended with R&D expenditure nearly $12 billion below the FY 2010 level.

Political challenges – and recent progress

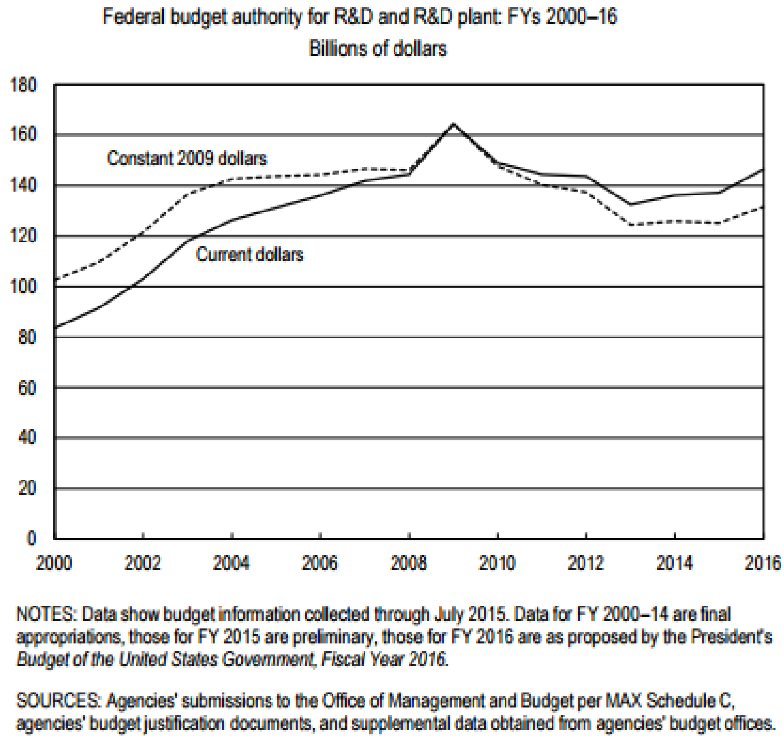
Maintaining an increasing annual level of federal funding for science has proven difficult given the substantial policy differences on budgetary matters within the Congress and with the President. The FY 2011 budget, which included the reductions known as "the budget sequestration," worked out to a decline of $4.6 billion in budget authority that year. After significant additional declines in 2013, more favorable circumstances emerged for FY 2014/15. Collectively on the order of $5 billion, these increases, while important in reversing the downward trend, did not outpace the rate of inflation. The

[46] A further observation is that the ICT component of U.S. research effort, of which Defense R&D is the largest share, is arguably underfunded.

[47] Macdonald, N. Ed. (2016, February 15) *Federal Technology Watch (FTW).* Volume 14. Issue 7

chart below shows the current trends in funding for R&D activity and R&D plant.[48] As the figure shows, the U.S. R&D effort declined substantially from its 2009 highs. On the other hand, there now seems to be a growing political will to return federally funded R&D to a more positive growth track.

Figure 10 Federal Budget Authority for R&D/R&D Plant (2000 – 2016)



Progress on increased funding for R&D

The growth in bipartisan understanding of the need to augment the nation's R&D budget became dramatically apparent in the bipartisan budget deal that passed the Congress in December of 2015. It appears to launch the U.S. on a much more positive path for the nation's R&D budget going forward. R&D expenditure rose very substantially across all major agencies (with the relative exception of NSF.) The clear winner was the National Institutes of Health (NIH), which received a $2 billion increase, representing a 6.6% increase of the NIH total budget.[49]

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[48] R&D plant is a small but essential input for R&D activity. In 2015 for example R&D spending was $134.7 billion for R&D with $2.4 billion in addition for R&D plant. R&D plant investments are normally for newer or upgraded facilities and large-scale equipment for basic research in a variety of fields by the National Science Foundation and the Department of Energy.

[49] This represents the largest increase to the NIH budget in 12 years. One should note however that the NIH budget, adjusted for inflation, had fallen 22% since 2003.
Mervis, J. (2015, December 18). Updated: Budget agreement boosts U.S. science. Retrieved May 10, 2016, from http://www.sciencemag.org/news/2015/12/updated-budget-agreement-boosts-us-science

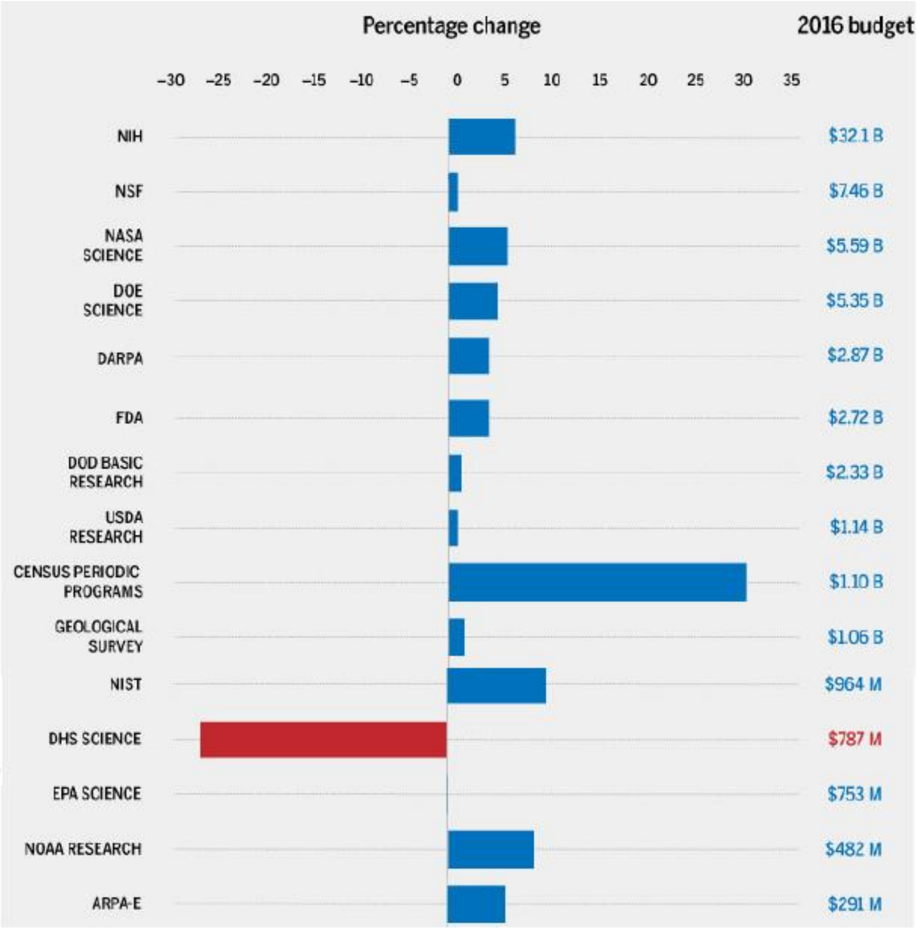
New Priorities

The new legislation will support a variety of new priorities at the National Institutes of Health. They include $350 million in new spending for research on Alzheimer's disease, a 60% increase over the 2015 amount, and substantially larger than the President's request of $51 million. It also contains the $200 million requested by President Obama for the Precision Medicine Initiative, an $85 million in new funding for the BRAIN Initiative, and a $100 million increase in NIH's role in the federal initiative on antimicrobial resistance. The rest of the new funds for NIH will be spread across NIH's twenty-eight institutes and centers, most of which will receive an increase of roughly 4%.

In January 2016, an initiative described as a "moonshot" was launched to combat cancer.
This effort is supported with a $1 billion initiative to provide funding for researchers to accelerate development of new cancer detection and treatments. This includes $195 million in new cancer activities at the NIH in FY 2016, $755 million in mandatory funds in the 2017 budget for new cancer-related research activities at NIH and the FDA, and support from agencies such as Defense and Veteran Affairs. Key goals of the Cancer Initiative Taskforce are to:

- Accelerate our understanding of cancer, its prevention, early detection, treatment and cure;
- Support greater access to new research, data, and computational capabilities;
- Improve patient access and care;
- Identify and address any unnecessary regulatory barriers and consider ways to expedite administrative reforms;
- Identify opportunities to develop public-private partnerships and increase coordination of the Federal Government's efforts with the private sector, as appropriate.

Figure 11 R&D Spending Variation by Agency (2016)



2.2.1 Research funders

Business R&D spending in the United States exceeded $300 billion in 2012.[50] To be more precise, companies spent $302 billion on R&D performed within the United States during that year. This represents a 2.8% increase from the $294 billion spent during 2011 (see table below). Funding from the companies' own sources was $247 billion during 2012, a 3.6% increase, while funding from other sources was $55 billion in both 2011 and 2012.

[50] National Center for Science and Engineering Statistics. National Science Foundation. October 2014. NSF 15-303.

Figure 12 Funds Spent for Business R&D by Source and Size (2011 – 2012)

Funds spent for business R&D performed in the United States, by source of funds and size of company: 2011–12
(Millions of U.S. dollars)

Selected characteristic	2011		2012	
Domestic R&D performance[a]	294,093		302,250	
Source of funds				
Paid for by the company	238,768		247,280	
Paid for by others	55,324		54,970	
Federal	31,309	i	30,621	i
Other[b]	24,015		24,349	
Size of company (number of domestic employees)				
5–24	10,981		9,841	
25–49	10,861		7,195	
50–99	9,468		9,182	
100–249	12,528		12,480	
250–499	12,955		11,264	
500–999	10,027		11,484	
1,000–4,999	50,485		50,691	
5,000–9,999	24,951		30,483	
10,000–24,999	49,214		49,493	
25,000 or more	102,623		110,138	

i = more than 50% of value imputed.

[a] For companies located in the United States that performed or funded R&D.

[b] Includes companies located inside and outside the United States, U.S. state government agencies and laboratories, foreign government agencies and laboratories, and all other organizations located inside and outside the United States.

Companies in the manufacturing industries performed $208 billion, or 69% of domestic R&D. Of the R&D performed in the 50 states and Washington D.C., 82% of the private R&D was from companies' own funds. The U.S. federal government served as the chief source for outside funding of R&D across all industries. The federal funding was concentrated on professional scientific and technical services and computer and electronic products; they received 89% of the federal R&D. Next among outside funders were foreign companies, spending $12 billion.

Business R&D by Company Size

R&D expenditures varied sharply by company size, with small companies (from 5 – 499 domestic employees) performing 17% of the nation's total business R&D in 2012. For these companies, the R&D intensity was 4.7%, compared to 3.1% for all other companies. The small companies accounted for 11% of sales but employed 17% of the 18.3 million who worked for R&D-performing companies.[51] There are some 1.5 million R&D employees, engaged in business R&D in the United States, and of these, 30% worked for small companies. Mid-sized companies (from 500 – 2,500 employees) accounted for 49% of sales and employed 41% of those who work for R&D-performing companies.

[51] Ibid. Page 3.

Business R&D by State

Across the United States, business R&D concentrates in a relatively small number of states. In 2012, companies reported $247 billion of domestic R&D paid for by the company. Of this, California alone accounted for over 28% of this amount. Much smaller amounts were spread across Massachusetts (5.7%), New Jersey (5.6%), Michigan (5.4%), Washington (5.5%), Texas (5.2), and Illinois (4.8%).

2.2.2 Funding sources and funding flows

Primacy of Private Investment

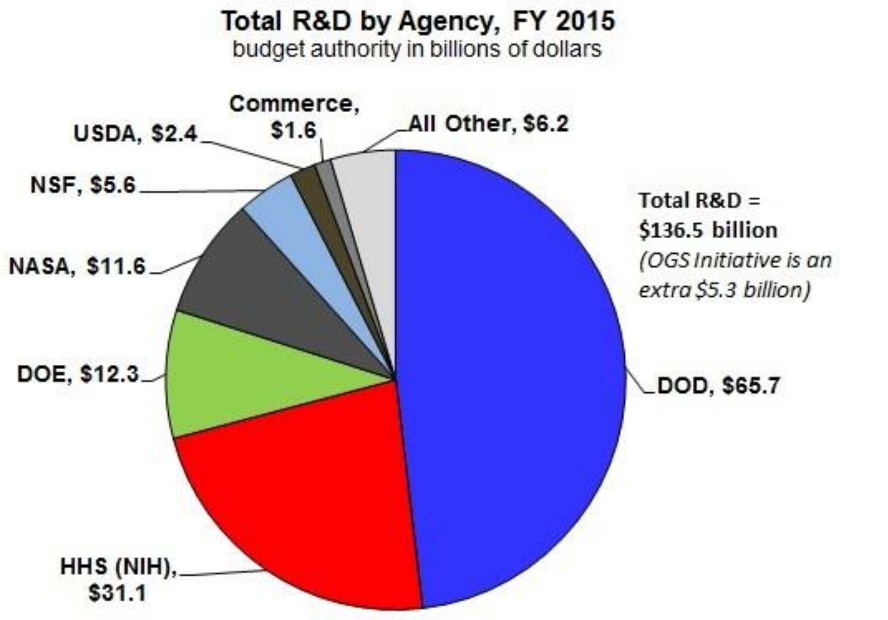
Over a third of US R&D is funded by the federal government, primarily through mission agencies, although substantial funds are available for basic research from the National Science Foundation and Department of Energy. The US private sector performs about two thirds of US R&D, supplemented by contributions from private foundations and support for state educational institutions.[52] This represents an historical shift from the 1960s, when the ratios were reversed. Recent years have seen steady downward pressure on R&D budgets after a high point reached in the 2009 budget cycle, as noted above. The good news is that recent policy compromises have resulted in significant increases in R&D for FY 2016. These agreements were driven by short term political consideration, but also significant adjustments in the deficit and continued respectable growth in US GDP, which has also resulted in significant reductions to unemployment. The pie chart below shows the relative position of R&D expenditure (34%). The scale of the expenditures, sometimes overlooked, exceeds the R&D budgets of Japan, France, and the United Kingdom combined. From an American perspective, there are no grounds for complacency however, as China's research investments and output as measured in publications and patenting have continued to expand at a rapid rate.

2.3 Public funding for public R&I

The chart below essentially speaks for itself. Recent changes in relative allocation are discussed in section 2.2 above. From a European perspective, it is worth noting that the Defense R&D budget includes many categories, including major investments in basic research as well as applied research on women’s health, disease prevention, e.g. vaccines for AIDS, and equipment for fighting highly infectious diseases such as Ebola.

[52] For the most part, state governments tend not to invest in research, and certainly not on the scale of the federal government. States normally invest in facilities and equipment in the hope of attracting federal or private R&D funds. There are exceptions. Some states such as California have launched multi-year research efforts on stem cells for example, although this was in part a response to the Bush administration’s proscriptions on stem cell research.

Figure 13 Total R&D Performed by Agency (2015)



Source: OMB R&D data, agency budget justifications, and other agency documents and data. R&D includes conduct of R&D and R&D facilities.

In terms of U.S. and EU cooperation, there sometimes appears to be a disconnect between the scale of the agencies' R&D portfolio and its openness on one hand, and the focus of cooperative initiatives by European counterparts.

Many European universities and research institutes seek to cooperate with the National Science Foundation, reflecting its deserved reputation for funding excellent science. The NSF, however, is one of the mid-level funders for U.S. research and is constrained in that it normally cannot send substantial funds overseas. The NIH on the other hand is more than four times larger in terms of research funds and often funds overseas research. Other agencies such as the Office of Naval Research and other U.S. military agencies can fund open source research for publication.

The difference in scale is striking. For example, in the case of NSF, the agency awarded €21.7m ($27.1m) a year on average over the 2007-2012 period to investigators outside the US or 0.5% of all moneys awarded through the agency's funding programs[53]. Over the last 2007-2012 time period, investigators in EU member states received an average of €7.5m ($9.4m) per year of this funding. The top countries in terms of NSF research dollars awarded from 2007-2012 were Austria, Denmark France, Germany, Italy, Sweden and the United Kingdom. The NIH awarded €210.1m ($262.6m) a year on average to investigators outside the US over the same time period or 1.3% of all moneys it awarded through its funding programs. Of this amount, €51.8m ($64.7m) a year on average went to investigators in EU member states[54]. The top countries in terms of NIH research dollars awarded from 2007-2012 were: Denmark, France, Germany, Italy, the Netherlands, Sweden and the United Kingdom.

In terms of implementation, common instruments used to implement agreements include research projects, task forces, studies, workshops/symposia/ conferences/seminars, visits and exchanges, and equipment and materials sharing for implementation. Training of scientists and technical experts is also used. For federal agencies, the most substantial indicator of cooperation is the level of foreign participation in national R&D programs.

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[53] National Science Board. (2016). *NSF Indicators, 2015.*

[54] Ibid.

2.4 Public funding for private R&I

As noted above, small businesses are major drivers of innovation and economic growth. In recent years, as the U.S. economy recovered from the "Great Recession" private capital has focused on the opportunities presented by innovative small businesses. While the United States is correctly known for its broad reliance on private sector markets in generating competitive outcomes, the role of the government in driving innovation is less widely recognized. This is particularly true in the case of small business finance, where the government provides highly-competitive awards to innovative small companies in order to address societal and government needs. The scale of the program is also underappreciated. It provides funding to startups (20-25%) and to small U.S. companies (under 500 employees in the U.S.) to develop new products and processes that address mission needs of 11 federal agencies. The top five agencies (The Department of Defense, The National Institutes of Health, NASA, The Department of Energy, and The National Science Foundation) make up 96% of the program. Some 6,500 companies receive awards annually. The current program is approximately $2.8 billion per year and is funded by imposing an allocation or a "tax" on agencies that have an external research budget over $100 million.[55]

2.4.1 Direct funding for private R&I

Privately funded corporate research is an essential, even dominant, element in the global research and innovation system. Corporate investment decisions are dramatically changing the geographic footprint of innovation as it becomes rapidly more global[56]. The reasons for these shifts are well known. Companies are shifting their innovation investment to countries in which their sales and manufacturing are growing fastest and where they can access the right technical talent. As a result, innovation spending has boomed in China and increasingly in India over the last 7 years. Indeed, collectively, more R&D is now conducted in Asia than in North America or Europe.

Given these trends, it is somewhat surprising to see that innovation spending in the U.S. has held relatively steady as a share of global innovation investment, and this is despite the major increases in the amount of R&D that U.S. firms conduct in Asia. The relative strength of the U.S. position is due to the fact that companies from other countries are increasing their R&D activity in the United States. More European companies are choosing to expand their R&D locations outside Europe, some in low-cost Asian countries, but also in high-cost countries like the United States.

2.4.2 Indirect financial support for private R&I: The R&D tax credit

The U.S. R&D tax credit has suffered from decades of uncertainty and political squabbling. Since it was created in 1991, the tax credit has lapsed six times, most recently last year, and has been temporarily extended 17 times.[57] The short renewals and the uncertainty created by lack of consensus in Congress arguably reduce the impact of the tax credit, particularly for longer term investment plans. Industry groups, economists, and advocates for research have all pressed the Congress to make the tax credit permanent. Despite bipartisan backing for the concept, in the recent budget cutting environment, the cost of making the credit permanent was a major obstacle.

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[55] Initially the SBIR program provided for a set aside of 0.2% of funding for agencies with extramural R&D budgets in excess of $100 million. In 1983, the program's first year funding totaled $45 million. Over the next six years, the set aside grew to 1.25%.

[56] PricewaterhouseCoopers (PwC). (2015). *The 2015 Global Innovation 1000*. Strategy business magazine. 94% of the world's largest corporate innovators now conduct important elements of their R&D programs abroad.

[57] Mervis, J. (2015, December 18). Updated: Budget agreement boosts U.S. science. Retrieved May 10, 2016, from http://www.sciencemag.org/news/2015/12/updated-budget-agreement-boosts-us-science

Currently, the credit costs the government some $7 billion in tax revenue annually. It is also among the most expensive to operate of all U.S. tax credits. Some estimates expect the decision to establish its permanence will cost the Treasury $100-150 billion over 10 years. Other analysts argue that these costs would be far outweighed by the benefits, suggesting that a permanent R&D tax credit will increase U.S. GDP by 0.16% annually and add some 36,000 jobs each year. In light of this decision, the National Association of Manufacturers in Washington D.C. stated that, "Short of comprehensive tax reform, this is one of the most significant steps Congress has taken in decades to improve our out-of-date tax code for businesses."[58]

2.4.3 R&D returns to business

The recent analysis of these trends shows that for high spending R&D companies, implementing a global innovation strategy offers significant returns in terms of higher performance than less globalized competitors, based on a variety of financial measures. The locational element is important because the authors found no statistically significant evidence that higher levels of spending necessarily produced better results. They argue that it is not how much you spend on research, but how well you spend it, but they also suggest their 2015 study shows that decisions about where the R&D is carried out are very different today than they were in 2007. The authors note that companies headquartered in the US, Europe, and Japan account for a large majority of innovation spending, however, their share of R&D spending has fallen from 96% in 2005 to 86% in 2015. North American companies share edged down from 42% to 40% while European shares remained flat and Japanese companies fell from 26% revenue to 24%. However, measuring on the basis of company headquarters can mask very substantial shifts in the actual location of spending.

Locational Shifts in R&D

The reason for this shift are many. Surveyed corporate R&D practitioners cited proximity to a high growth market as a top reason for moving R&D to China, following by proximity to manufacturing sites and key suppliers. They also cited lower development costs, although this was not the primary reason for many investments.

Despite these trends, the US has held on to its position as the number one location for innovation expenditure, despite the fact that US headquartered companies invested over 120 million in overseas R&D in 2015. Much of the US overseas investment has shifted, with less going to the UK and France, and more now being allocated to China, India, and South Korea. The US' leading position was buttressed by a 23% rise in the "imported R&D" from other countries. The largest gains to the US innovation enterprise came from European companies investing in the US. Germany for example massively increased its investments in US R&D and is now the leading source of R&D investment in the US, surpassing Japan, which led by a large margin in 2007. [59]

European R&D Investments in the U.S.

The surge of R&D investments from Europe into the US underscores the fact that cost is typically not the main driver in R&D decisions. The US is a high cost country for R&D and does not have as favorable an R&D tax regime as some countries in Europe. European R&D investment seems to be driven, as it is in China, by the need for proximity to their markets and operations, access to exceptional talent and technology, and to take advantage of outstanding university systems and their positive innovation culture.

The U.S. government's substantial and sustained investment in research has helped generate innovation ecosystems that prove attractive. Representatives of major pharmaceutical companies cite the NIH investment in academic research and its impact

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[58] Ibid.

[59] National Science Board. (2016). *Science & Engineering Indicators 2016.* Page 9. Retrieved from http://www.nsf.gov/statistics/2016/nsb20161

on the "strategic direction" of the US innovation system. "There are strong academic laboratories, a vibrant biotech industry, global pharmaceutical companies, and strong engagement from philanthropic organizations and patient foundations." Others point out that the US is attractive for global R&D, not only for its large and growing market, but also for its digital skills. Where the US has large numbers of "digital natives", another, more fundamental attraction is the general openness of the US society towards innovation. This is reflected in regulatory regimes and early market acceptance as well. Recognizing these advantages, European, Japanese, and increasingly Chinese firms are making substantial R&D investments in the United States.

3. Framework conditions for R&I

The United States' innovation ecosystem greatly benefits from a policy environment that facilitates openness to science and innovation and encourages the commercialization of new ideas. For starters, there is a generally high level of public trust in science and scientific institutions. This translates to openness towards innovation, which in turn facilitates the entry and uptake of innovative new products. U.S. culture also holds positive social norms with regard to innovative new businesses. Broadly speaking, Americans place a high social value on commercial success.

Below are some of the instrumental pieces of legislation that have shaped innovation policy and the direction of R&I practices in the United States:

Framework Conditions: The Legislative Record of Principal Federal Legislation Related to Cooperative Technology Programs[60]

• Stevenson-Wydler Technology Innovation Act (1980)

Required federal laboratories to facilitate the transfer of federally owned and originated technology to state and local governments and the private sector. The Act includes a requirement that each federal lab spend a specified percentage of its research and development budget on transfer activities and establish an Office of Research and Technology Applications (ORTA) to facilitate such transfer.

• Bayh-Dole University and Small Business Patent Act (1980) Permitted government grantees and contractors to retain title to federally funded inventions and encouraged universities to license inventions to industry. The Act is designed to foster interaction between academia and the business community. This law provided, in part, for title to inventions made by contractors receiving federal R&D funds to be vested in the contractor for small businesses, universities, or not-for-profit institutions.

• Small Business Innovation Development Act (1982) Established the Small Business Innovation Research (SBIR) Program within the major federal R&D agencies to increase government funding of research with commercialization potential in the small high-technology company sector. Each federal agency with an R&D budget of $100 million or more is required to set aside a certain percentage of that amount to finance the SBIR effort.

• National Cooperative Research Act (1984) The National Cooperative Research Act of 1984 eased antitrust penalties on cooperative research by instituting single, as opposed to treble, damages for antitrust violations in joint research. The Act also mandated a "rule of reason" standard for assessing potential antitrust violations for cooperative research. This contrasted with the per se standard by which any R&D collusion is an automatic violation, regardless of a determination of economic damage.

• Federal Technology Transfer Act (1986) Amended the Stevenson-Wydler Technology Innovation Act to authorize cooperative research and development agreements (CRADAS) between federal laboratories and other entities, including state agencies.

• Omnibus Trade and Competitiveness Act (1988) In addition to establishing the Competitiveness Policy Council designed to enhance U.S. industrial competitiveness, the Act created several new programs (e.g., the Advanced Technology Program and the Manufacturing Technology Centers) housed in the Department of Commerce's National Institute of Standards and Technology and intended to help commercialize promising new technologies and to improve manufacturing techniques of small and medium-sized manufacturers.

[60] Wessner, C. Ed. (2000). An Assessment of the Department of Defense Fast Track Initiative. National Academies Press.

• National Competitiveness Technology Transfer Act (1989) Part of the Department of Defense authorization bill, this act amended the Stevenson-Wydler Act to allow government-owned, contractor-operated laboratories to enter into cooperative R&D agreements.

• Defense Conversion, Reinvestment, and Transition Assistance Act (1992) Initiated the Technology Reinvestment Project (TRP) to establish cooperative, interagency efforts that address the technology development, deployment, and education and training needs within both the commercial and defense communities.

3.1 General Policy Environment for Business

Internationally mobile students

The United States has a supportive regulatory environment, particularly with regard to new companies. It remains relatively easy to start a company in the United States with minimal fees and processing time. Labor regulations are also flexible, allowing rapid hiring on short-term or at-will contracts that permit companies to grow, contract, grow to scale, and contract again, depending on market conditions and the pace of technological change. And not least, the gentle bankruptcy laws that characterize the United States, notably Chapter 11, facilitate the rapid exit of firms while enabling the human managerial and intellectual capital to recommit to new endeavors in a relatively short time frame. This relative ease of beginning, and especially ending, a company serves to mitigate the risks associated with startup activity. In part because of these factors, investors are often willing to consider failure a valuable learning experience (indeed, some suggest it is more valuable than a successful experience). It certainly lowers the social stigma associated with commercial failure. This is particularly true in states with many entrepreneurs: areas such as California, Washington, and Colorado, but less so in more traditional areas such Pennsylvania, Ohio, and the Midwest. In any case, the relatively low social cost and the ability to attract new funding encourages entrepreneurial activity.

Notwithstanding the difficulties of remaining in the U.S., as outlined above, graduate education in the United States remains particularly attractive to international students. Unlike science and engineering bachelor level degrees, the United States actually awards a larger number of S&E doctorates than China (see below). However, as described above, a substantial portion of U.S. S&E doctoral degrees are conferred to international students with temporary visas. In 2013, temporary visa holders, not counting foreign-born students with permanent visas, earned 37% of S&E doctoral degrees.[61] Temporary visa holders are particularly concentrated in engineering, computer sciences, and economics. As a recent National Science Board report notes, "in 2013, temporary residents earned half or more of the doctoral degrees awarded in these fields. Overall, nearly half of the post-2000 increase in U.S. S&E doctorate production reflects degrees awarded to temporary visa holders, mainly from Asian countries such as China and India. If past trends continue, however, a majority of the S&E doctorate recipients with temporary visas – more than 60% – will remain in the United States for subsequent employment."[62] This represents a significant gain in intellectual capital to the U.S. economy. It also entails a major transfer of resources, both intellectual and financial, for the degree-holders who return directly to their country of origin.[63]

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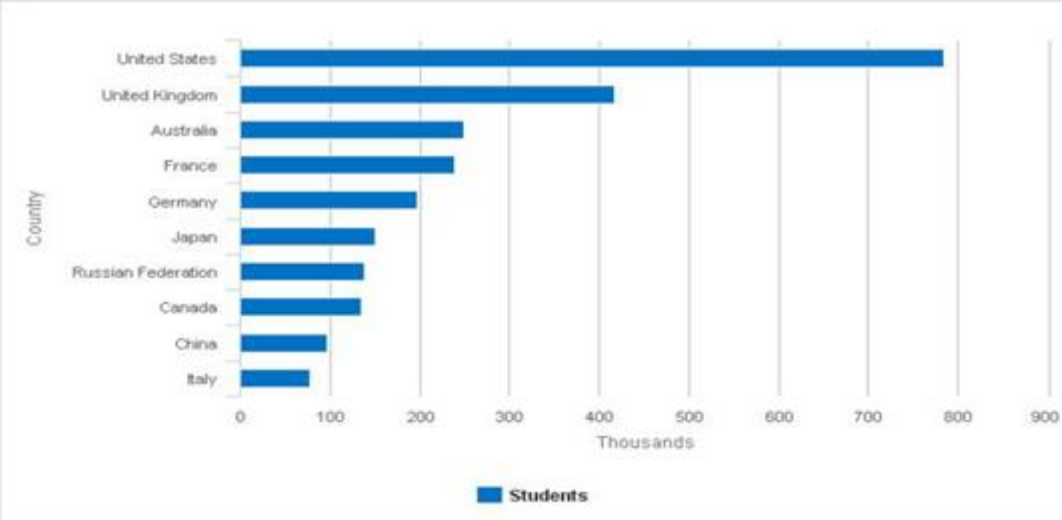
[61] National Science Board. (2016). *Science & Engineering Indicators 2016.* Page 9. Retrieved from http://www.nsf.gov/statistics/2016/nsb20161

[62] Ibid, page 10.

[63] Even when full tuition is paid by the student, which is frequently not the case, the cost of a doctoral education in the applied sciences normally exceeds the cost of tuition. This is why some leading university

Figure 14: Internationally Mobile Students (2013)

Internationally mobile students enrolled in tertiary education, by selected region/country/economy: 2013



NOTES: Data are based on the number of students who have crossed a national border and moved to another country with the objective of studying (i.e., mobile students). Data for Canada, Italy, and Japan correspond to 2012.

SOURCE: United Nations Educational, Scientific and Cultural Organization Institute for Statistics database, special tabulations (2015).

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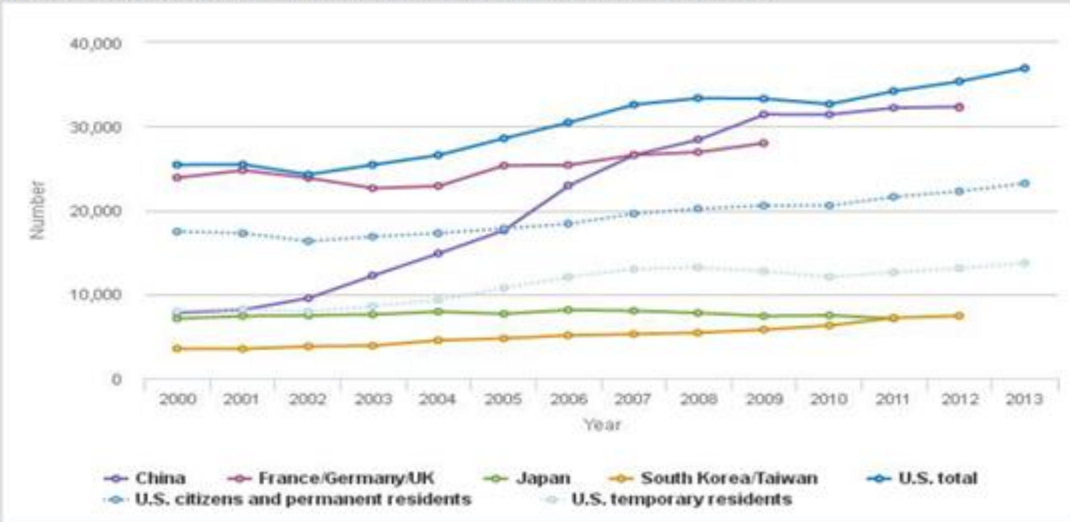
Figure 15 : Doctoral degrees in S&E (2000-2013)

Doctoral degrees in S&E, by selected region/country/economy: 2000–13



NA = not available.

UK = United Kingdom.

NOTE: Data are not available for all regions/countries/economies in all years.

SOURCES: Organisation for Economic Co-operation and Development, Education Online database, http://www.oecd.org/education; national statistical offices.

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presidents argue that when doctoral degrees in STEM education are awarded, they should include a Green Card.

3.2 Young innovative companies and start ups

Startup activity surged in the United States in 2015[64]. Startup activity saw its largest year over year increase in the last two decades. The surge was all the more notable in that it reversed a 5 year downward trend in U.S. entrepreneurial activity. This sharp rise gives some hope for a longer term revival of entrepreneurship in the U.S, although the increased activity remains well below historical standards. Principal drivers of the growth in startup activity were opportunity based entrepreneurship (i.e. not driven by unemployment) and the continued strength in immigrant entrepreneurship.

Composition of entrepreneurs

In the 2015 survey, 63% of new entrepreneurs were male. Paradoxically, the share of the new entrepreneurs who are female fell from 44% to 37%, which is close to a two decade low. New entrepreneurs in the United States continue to come from very different educational backgrounds. However, since 1997 the share of new entrepreneurs who are college graduates increased from 24% to 33%, making entrepreneurs with college degrees the largest educational category of new entrepreneurs.

The age of new entrepreneurs remains basically split evenly in 2015. Younger entrepreneurs (ages 20-24) have been on the decline. This cohort has declined from 34% of all entrepreneurs in 1997 to around 25% in the 2015 index. At the same time, the aging of the U.S. population, combined with a rising rate of entrepreneurship among individuals aged 55-64 have shifted levels of entrepreneurship in this older group from around 15% of new entrepreneurs in 1997 to almost 26% of new entrepreneurs in 2015.

Importantly, immigrant entrepreneurs now account for 28.5% of all new entrepreneurs in the United States. This is more than double the 13.3% of immigrants observed in the 1997 index. This increase reflects, of course, the increasing population of immigrants, but also the much higher rate of entrepreneurship among this group. Immigrants continue to be almost twice as likely as native born Americans to become entrepreneurs[65].

The upsurge in entrepreneurship in the United States, while reassuring, has not yet returned to pre-Great Recession levels. The causes of the decline are complex and not well understood. Some observers argue that the rising levels of student debt may be contributing to the decline in entrepreneurship[66]. Heavily indebted graduates are seen as less likely to be willing to take the risk of starting a new company than those who are debt free. And increasing numbers of American students have increasingly onerous levels of debt upon graduation - with the worst situation being those who have failed to graduate but must still pay off student loans.

Framework Conditions: Sources of Entrepreneurship and Early Stage Finance

These national policies are bolstered by a strong intellectual property regime which encourages research and the subsequent diffusion of research results. Additionally, the U.S. promotes entrepreneurship with policies that ensure commercial markets are open to competition and tax regimes that offer the prospect of substantial rewards to entrepreneurs, along with the social recognition mentioned above. Crucially, early stage funding is available at multiple phases, both through government programs (SBIR), Angel investors and of course venture capital. The latter category has seen a surge in growth in 2014-2015, as discussed below.

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[64] This section draws from: Fairlie, R., Morelix, A., Reedy, E.J. & Russell, J. (2015). "The 2015 Kauffman Startup Activity: National Trends." *The Ewing Marion Kauffman Foundation.*

[65] Ibid.

[66] See for example Mitch Daniels, former Head of OMB (Office of Management and Budget) Ex-governor of Indiana, and current President of Purdue University.

It is difficult to overstate the importance of these framework conditions with regard to the environment for innovation. In the absence of these conditions, or at least a number of them, programs designed to encourage innovation may well be limited in their long-term impact.[67]

As noted above, small companies are key players in bringing new technologies to market. Small companies, particularly those who have key staff or management drawn from universities, are often highly innovative. Additionally, small, high-tech companies serve as a major mechanism to transfer knowledge developed in universities into products and processes that can be deployed in the marketplace. As Audretsch and Acs have argued in their seminal work, small companies are not the only source of new ideas and new technologies[68]. Large companies have them in abundance. However, small companies are frequently more focused and more committed to a particular technology or product, and are often more agile in seizing opportunities. This is largely a result of a flat hierarchy, which enables more rapid decision-making. In any case, the American economy benefits substantially from large numbers of highly competitive small companies and frequent surges of well-financed startups. These companies are able to create attractive products—often welfare enhancing technologies—and thus successfully create new jobs and new supply chains in a virtuous cycle. Their ability to challenge incumbents with new technologies increases market competition, providing pressure on incumbents in both price and quality. A relatively unique feature of the U.S. innovation system is the ability of innovative small businesses to expand over time. This is true of once small companies, such as Intel (1968), Microsoft (1974), and Qualcomm (1984). This ability to scale has become even more evident with the rapid growth of companies such as Google, Yahoo, and other social media firms such as Facebook, Twitter, LinkedIn, etc.[69]

A Boom in Venture Funding

A convergence of factors in information technology and capital markets have helped propel a boom in venture capital-backed startups in recent years. The upsurge in venture funding has accelerated across 2014 and 2015. In 2015, the venture capital ecosystem deployed $58.8 billion across the United States, making it the second highest full year total in the last 20 years.[70] While an extremely strong showing, 4th quarter 2015 VC investments slowed to $11.3 billion with 962 deals. This is down 32% in dollars ($) from the 3rd quarter, when $16.6 billion was invested. This inflow of capital is driven in macro terms by the generally positive economic environment in the United States, with sustained GDP growth around 2.5% and with unemployment now under 5%[71]. The rapid growth in investment is also being driven by the convergence of technology across sectors, creating opportunities for companies with innovative, disruptive technology and business models. The largest VC deals in the most recent quarter supported technologies that challenged incumbents in financial services, education, retail, and consumer industries. With almost $60 billion deployed to startup companies in 2016, the US Venture market system is remarkably robust, yet late-stage funding rounds are absorbing a significant portion of the VC funding. For example, in 2015 there were 74 megadeals (investments of $100 million or more) compared with 50 in 2014. That said,

[67] These strengths notwithstanding, the U.S. innovation system does face a growing challenge from opponents to innovation. The fears of privacy loss from the internet, growing concerns about automation, or concerns about environmental damage from fracking, or the potential risks from nanotechnologies have all grown substantially in the last decade. These anti-innovation forces have a growing impact on the media and, as they become better organized, the interest groups may well take on a self-sustaining character, which overtime could impede Americans' positive attitude and rapid take-up of new technologies.

[68] Acs, Z. J., & Audretsch, D. B. (1990). *Innovation and small firms*. Mit Press.

[69] Its important to note that while high-growth small firms create significant employment, they frequently disrupt other industries, displacing workers as well.

[70] PricewaterhouseCoopers (PwC). (2015). *Moneytree report, 2015.* National Venture Capital Association.

[71] Bureau of Economic Analysis (BEA.) (March 2016). *Employment Situation.*

the President of the National Venture Capital Association observed, that "more than half of all deals in 2015 went to seed and early stage companies."[72]

Industry Allocation

The software industry continued to receive the highest level of funding, with 4 of the top 10 megadeals going to software companies. The biotechnology industry continues to receive the second largest amount of venture funding, with $1.5 billion going into 95 deals.[73] Life Sciences, which include both biotech and medical devices, accounted for $2 billion in some 172 deals, with investments up 12% compared to 2014. Media and Entertainment companies received $818 million across 114 deals in Quarter 4. Venture Capital investors moved just under $3 billion into 229 internet-specific deals in the last quarter as well.

Stage of Development

Investments in seed stage companies rose by 55% in the 4th quarter with 52 deals totaling $375 million, which represented just 3% of all VC investments. Early stage investments were just under $5 billion with 494 deals. Early stage accounted for 57% of the total volume. The average seed stage deal at the end of 2015 was $7.2 million, up from $4.1 million in the 4th quarter, whereas the average early stage deal was $10 million. For all of 2015, the average amount invested in both seed and early stage deals rose 23% compared to 2014.

Geographic Allocation

While well-established regions such as San Francisco-Silicon Valley, Boston-Cambridge, and New York account for the lion's share of startup activity and funding, significant evidence suggests that a non-trivial amount of early stage capital is dispersing geographically throughout the United States.

As noted above, the contributions of venture capital to the U.S. innovation system are of fundamental importance; they are often sometimes overstated. One of the major advantages of venture investments is their ability to scale promising firms. In 2013, some $9.8 billion was invested in just over 2000 deals with early stage firms. Another $9.8 billion was invested in the expansion stage in 984 deals. Later stage investments totaled $8.8 billion across 790 deals. Importantly, however, the seed stage saw just over 200 deals for a total of $943 million[74].

This distribution reflects the normal focus of the venture industry on later-stage development in contrast to seed investments, where risks – and losses – are considerably higher than the already risky later stages. What this does underscore, however, is how the role of federal programs, such as the $3 billion annual SBIR program, and the many state investment agencies, and the $24 billion annual investment by angel investors represent key pillars of the U.S. innovation system. They provide the early stage funding that enables promising U.S. firms to cross the early stage funding gap referred to as the "valley of death" on a larger scale and with more accessibility, and often better terms, than those available from venture funds.

Startup activity surged in the United States in 2015. Startup activity its largest year over year increase in the last two decades. The surge was all the more notable in that it reversed a 5 year downward trend in entrepreneurial activity in the United States. This sharp rise gives some hope for a longer term revival of entrepreneurship in the U.S, although the revival remains well below historical standards. The growth in startup activity is driven by continued strong male opportunity entrepreneurship (i.e. not driven by unemployment) and the continued strength in immigrant entrepreneurship.

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[72] National Venture Capital Association (NVCA). (January 2016). $58.8 Billion in Venture Capital Invested Across U.S. in 2015, According to the MoneyTree Report.

[73] Ibid.

[74] See PriceWaterhouseCoopers "Money Tree Report, 2013".

Composition of entrepreneurs

In the 2015 survey, 63% of new entrepreneurs were male. Paradoxically, the share of the new entrepreneurs who are female fell from 44% to 37%, which is close to a two decade low. New entrepreneurs in the United States continue to come from very different educational backgrounds. However, since 1997 the share of new entrepreneurs who are college graduates increased from 24% to 33%, making entrepreneurs with college degrees the largest educational category of new entrepreneurs.

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Importantly, immigrant entrepreneurs now account for 28.5% of all new entrepreneurs in the United States. This is more than double the 13.3% of immigrants observed in the 1997 index. This increase reflects, of course, the increasing population of immigrants, but also the much higher rate of entrepreneurship among this group. Immigrants continue to be almost twice as likely as native-born Americans to become entrepreneurs. [75]

The upsurge in entrepreneurship in the United States, while reassuring, has not yet returned to pre-Great Recession levels. The causes of the decline are complex and not well understood. Some observers argue that the rising levels of student debt may be contributing to the decline in entrepreneurship. Heavily indebted graduates are seen as less likely to be willing to take the risk of starting a new company than those who are debt free. And increasing numbers of American students have increasingly onerous levels of debt upon graduation - with the worst situation being those who have failed to graduate but remain must still pay off student loans.

The Small Business Innovation Research Program (SBIR)

As noted above, small businesses are major drivers of innovation and economic growth. In recent years, as the U.S. economy recovered from the "Great Recession" private capital has focused on the opportunities presented by innovative small businesses. While the United States is correctly known for its broad reliance on private sector markets in generating competitive outcomes, the role of the government in driving innovation is less widely recognized. This is particularly true in the case of small business finance, where the government provides highly-competitive awards to innovative small companies in order to address societal and government needs. The scale of the program is also underappreciated. It provides funding to startups (20-25%) and to small U.S. companies (under 500 employees in the U.S.) to develop new products and processes that address mission needs of 11 federal agencies. The top five agencies (The Department of Defense, The National Institutes of Health, NASA, The Department of Energy, and The National Science Foundation) make up 96% of the program. Some 6,500 companies receive awards annually. The current program is approximately $2.8 billion per year and is funded by imposing an allocation or a "tax" on agencies that have an external research budget over $100 million.[76]

The program has been in place since 1982, although it was initially quite small. However, the allocation has increased over the years, which has led to remarkable success. A National Academies of Sciences review on the program found it to be: "Sound in concept

[75] Farlie, R. & Morelix, A. (2015). *The Kauffman Index, Startup Activity: National Trends*. The Kauffman Foundation.

[76] Initially the SBIR program provided for a set aside of 0.2% of funding for agencies with extramural R&D budgets in excess of $100 million. In 1983, the program's first year funding totaled $45 million. Over the next six years, the set aside grew to 1.25%.

and effective in operation."[77] The Program was created under the Small Business Innovation Development Act of 1982. It is the largest U.S. innovation program for small businesses. It offers competitive awards to support the development – and commercialization – of innovative technologies by small private-sector firms. A key goal of the program is to provide government agencies with technical and scientific solutions that address their different missions.

Program Goals

The legislation as noted above mandated four goals for the program. It is intended to: 1) Stimulate technological innovation; 2) Use small business to meet federal research & development needs; 3) Increase private sector commercialization of federally-funded research & development; and 4) Foster and encourage participation by minority and disadvantaged persons (women in technological innovation). These goals are pursued by all the agencies through a common program framework. Reflecting the program's administrative flexibility, the individual agency programs often differ from each other in important respects as they seek to address their unique mission needs.[78]

The SBIR program is highly-competitive. As it has gained in popularity, success rates have declined. For example, at the Department of Defense, which accounts for over 50% of the program, only 13% of phase 1 applications resulted in an award. Across the department, less than 50% of phase 2 applications were successful. An important feature for the SBIR program at the Department of Defense is that it allows a "sole-source contract." This means that companies that successfully complete their awards can be awarded follow-on procurement contracts with no further competition. This provides both an incentive to apply for the program and a means for enhancing competition on price and quality, as well as through the creation of new products in the Department's procurement system.

Structure of the Program

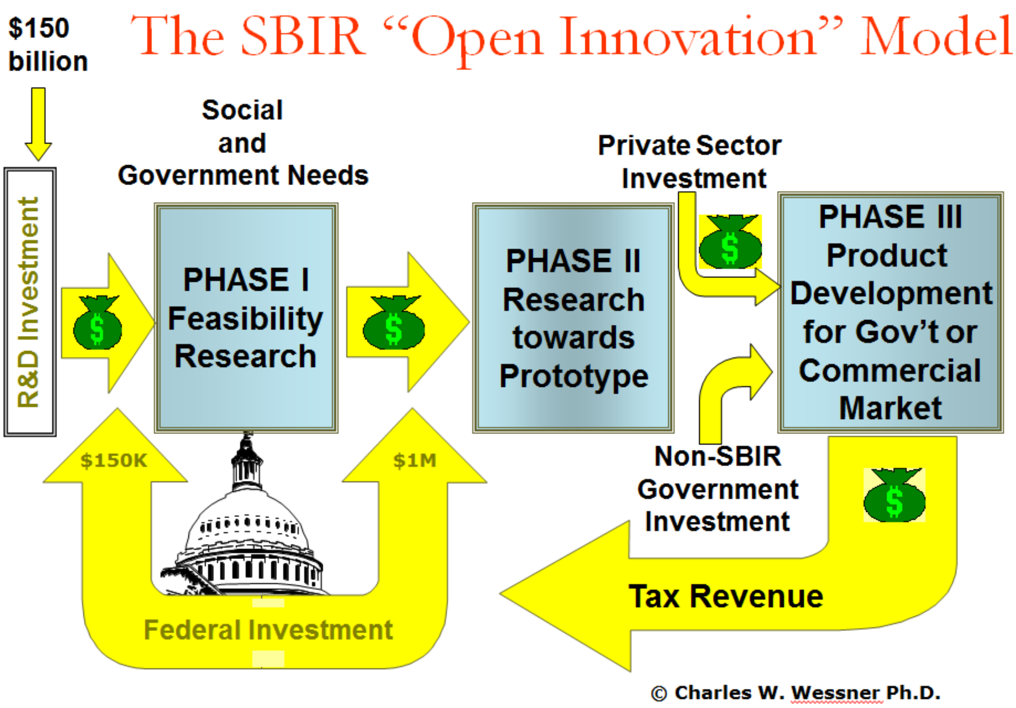
The program provides competitive, phased awards of increasing amounts for increasing levels of development. Phase 1 awards are for proof of principle. The firm normally receives $150,000[79] evaluation awards. Phase 2 awards are for development of prototype and are normally prized at $1 million, although this second phase shows considerable flexibility across agencies. Phase 3 awards focus on commercialization, although this is defined differently across different agencies. In the Department of Defense, phase 3 awards often – not always – offer partial SBIR funding to be complimented by funding from a procurement program as a means of winning acceptance for the innovation. At the NIH, the second largest program, substantial additional funds can be made available up to $3 million additional dollars in continuation awards. The additional awards funds are made available largely because the NIH has an extremely limited procurement budget, unlike the Department of Defense. Consequently, the NIH awards are used to push promising technologies towards the biosector market. The National Science Foundation also does not acquire products, but rather it uses what is called a "Phase 2 – B" program, which provides additional funding on the condition that matching funds can be acquired from the private sector. In each of these cases, theobjective is to provide a mechanism—first to develop and then to transfer, the innovative product to the private sector.

[77] Wessner, C. W. Ed. (2008). *An Assessment of the SBIR Program*. National Research Council. National Academies Press.

[78] Wessner, C. W. Ed. (2013). *An Assessment of the SBIR Program: SBIR at the Department of Defense.* National Research Council. National Academies Press.

[79] This amount was raised at the recommendation of the National Academies Study to $150,000.

Figure 16 The SBIR Model



Reflecting the different mission needs and modes of operation, award types vary among agencies. While the Department of Defense employs research contracts for its awards, the National Institutes of Health primarily uses grants. The contracting mechanisms also vary. It is important to note that the resources and time constraints imposed by the program are administered in a flexible fashion, with each of the different agencies addressing them in different ways. For example, both DoD and NIH make larger awards than the standard amount, whereas NSF normally makes smaller awards. Similarly, the NIH often provides no-cost extensions to allow time for research to be completed and frequently makes "continuation awards" that provide substantial additional resources. This flexibility is a key source of the program's success.

Startup Accelerator Programs

I-Corps Program[80]

The National Science Foundation is planning to expand the agency's innovation ecosystem by funding new hubs of what it calls the "Innovation Corps" (or the I-Corps for short). This is a series of training programs combined with other initiatives that is designed to rapidly translate products of NSF-funded research from the university laboratories to the commercial world. The I-Corps training is designed to convert university researchers' promising ideas to practical products that not are only interesting technologically, but which are also poised to have a market appeal. A key part of the I-Corps training focuses on understanding the needs of potential customers through repeated direct contact, rather than developing a product first and then seeing if it wins market acceptance.

[80] Serial entrepreneur Steve Blank, who helped NSF create the program based on one of his classes at Stanford that trained NSF scientists to move forward with their NSF-funded research in an entrepreneurial way, called the I-Corps one of the government's "most audacious experiments in entrepreneurship since World War II."

The program has shown considerable success. As of August 2015, NSF reported that more than 1,600 participants had completed the program. The graduates then formed some 260 startups that raised more than $49 million in outside funding. NSF Director France Córdova said in a recent statement, "The I-Corps model has spread because of the people from all fields of science and engineering who have gone through the training and have been truly transformed by the experience," going on to emphasize, "The power of these success stories compels more people to bring I-Corps to their communities."[81] Reflecting this positive assessment, NSF is offering up to $8 million in cooperative agreement awards to enable researchers to perform new I-Corps nodes. These are central hubs meant to serve regional needs for innovation and education through the preparation of I-Corps teams.

The relatively small capital investments often seed into larger, multiplied investments down the road when participants build startups around their experiences in the program. As of August 2015, NSF said more than 1,600 people had completed the program and formed 261 resulting startups that raised more than $49 million in outside funding to promote the quicker movement of innovation to the commercial market. Successful I-Corps teams have gone on to build businesses in a range of industries ranging from the sale of 47rapheme film to the development of an open-source cloud platform.

3.3 Knowledge transfer and open innovation

U.S. research universities are a major national asset in the ongoing quest for innovation and growth.[82] The strength of the U.S. university system and its close interaction with the national economy is not an accident of history. It is the result of forward-looking and deliberate federal and state policies that began with the Morrill Act of 1862, paving the way for a new wave of U.S. educational institutions commonly known as the "land grant universities"[83]. This act, which marked the first major step towards democratizing the U.S. educational system, established partnerships between the federal government and states to promote universities to focus on the growth of modern agriculture and the needs of industry.

In World War II, the universities and their scientists played major roles. The government–university partnership was expanded in the 1950s and 1960s to contribute to national security, then to public health, and, over time, as a source of economic growth. Sustained federal support for basic research through the Cold War resulted in a major funding role for the federal government, one which was largely concentrated in the nation's 250 research universities. An important addition to this partnership involved the growth of support by industry and philanthropists. Industry-funded research brings a necessarily pragmatic function to university research, but one that nonetheless generates substantial publications in peer-reviewed journals.[84] Particularly for the private universities, contributions from wealthy individuals often enable university leadership to undertake new programs, build out new, high-cost research facilities (that then enable

[81] National Science Foundation. (4, August 2015). *National network of entrepreneurs shines at White House Demo Day*. Press release.

[82] The U.S. maintains a strong leadership education in world class universities. According to some surveys, 13 of the top 20 universities are in the U.S. "Harvard, MIT, Yale, U-Chicago, U-Penn, and Colombia are 6 out of the top 10 worldwide."

[83] Wessner, C.W. Ed. (2012). *Rising to the Challenge: US Innovation Policy for the Global Economy.* National Research Council.

[84] Faems, D., Van Looy, B., & Debackere, K. (2005). Interorganizational collaboration and innovation: toward a portfolio approach. *Journal of product innovation management*, They point out that the university teams that cooperate with industry publish more peer-reviewed articles than teams that do not engage in such cooperation. In short, there is no tradeoff between cooperation with industry and science quality. See his Dr. Debackere's presentation in: National Research Council. (2008). Innovative Flanders: Innovation Policies for the 21st Century: Report of a Symposium. Washington, DC: The National Academies Press.

the university to compete for federal resources), and to provide the financial reserves necessary to attract and maintain top level academic talent from around the world.

This federal partnership, complimented by the contributions and perspectives of industry and philanthropists, has led to great benefits for the U.S. economy and the world's quality of life as a whole. The range of major advances is impressive. As the former provost of Colombia University, Jonathan Cole, has observed, "The laser, magnetic-resonance imaging, FM radio, the algorithm for Google searches, global positioning systems, DNA fingerprinting, fetal monitoring, bar codes, transistors, improved weather forecasting, mainframe computers, scientific cattle breeding, advanced methods of surveying public opinion, even Viagra, had their origins in America's research universities." He points out that these are only a few of the tens of thousands of advances originating in U.S. and other universities that have transformed the modern world.[85]

Technology Commercialization

As the discussion above strongly suggests, U.S. universities substantially contribute to the creation of not only new technologies, but also new companies—even new industries—and the jobs they engender. According to the Association of University Technology Managers (AUTM), since 1980 U.S. universities have spun off nearly 5,000 new companies. This trend has accelerated in recent years, with 914 new companies launched in 2014. In the same year, some 965 new products based on university discoveries were introduced to the market. Over the last 20 years, AUTM reports more than 80,000 U.S. patents were issued to research institutions[86]. The economic impact of university and non-profit patent licensing between 1996 – 2013 is estimated at some $518 billion.[87] Major contributors to this process of commercializing research are the presence of active technology transfer professionals who can contribute to securing the patents and providing advice on potential sources of funding to inventors. A major source of early stage funding is the U.S. Small Business Innovation Research Program for small companies and startups, and there is increasing availability of early stage early stage and seed investments by the venture community.

Performance-based Funding in the United States[88]

For the most part, performance-based funding as it is used in a number of European countries is not in widespread use in the United States. Federal support to research in Higher Education Institutions in the US is by and large allocated in the form of project funding.[89] This leaves little room for the Federal government to allocate institutional funding on the basis of a Performance Based Regime. Moreover, it would represent an expansion of federal purview over the research universities that would be unwelcome. Increasingly, however, some of the 50 state governments do provide institutional funding to the colleges and universities that constitute their higher education systems.

Historically individual states provide institutional funding in relation to the number of full time (equivalent) students the universities enroll. This model has changed in many states to incentivize universities to help students to complete degree programs (i.e. in many states it now also considers degrees awarded). Increasingly, states are including

[85] Cole, J. (3 Jan, 2010). Can American Research Universities Remain the Best in the World? The Chronicle. Web.

[86] Biotechnology Industry Organization. (March 2015). The Economic Contribution of University/Nonprofit Inventions in the United States: 1996-2003

[87] Association of University Technology Managers (AUTM). (2014). U.S. Licensing Activity Survey Highlights FY2014.

[88] Hicks, D. (2011). Performance-based university research funding systems. Research Policy.

[89] Woodhouse, K. (12 June, 2015). Federal spending has overtaken state spending as the main source of public funding in higher education. Web. InsideHigherEd.

criteria that are tied to the goals and priorities of the state's higher education policy makers in the funding allocation mix.

As specified, "Thirty-two states have a funding formula or policy in place to allocate a portion of funding based on (primarily education) performance indicators such as course completion, time to degree, transfer rates, the number of degrees awarded, or the number of low-income and minority graduates.[90] Five additional states—Connecticut, Georgia, Iowa, South Dakota, and Vermont—are currently transitioning to some type of performance funding, meaning the Legislature or governing board has approved a performance funding program and the details are currently being worked out." In most of the U.S. states the funding allocation formula adopted to distribute funding to HEI are thus based on quantitative input and education indicators, potentially tied to the strategic objectives of the states government such as addressing labor market shortages for STEM students or for promoting the share of disadvantaged students. As Hicks notes, the literature suggests that performance-based reviews focused on academic excellence may actually enhance control of professional elites and compromise other values such as equity or diversity. Moreover, they do not serve the goal of enhancing the economic relevance of research.[91]

The Entrepreneurial University

The U.S. concept of an entrepreneurial university is gaining ground, albeit slowly, among leading countries. While certainly not a codified concept, an entrepreneurial university provides a culture of entrepreneurial activity at the university, enabling it to undertake what some call "entrepreneurial science." That is problem-based, high-impact research on pressing global problems. The research and development are designed to produce measurable outcomes with a focus on products such as vaccines, pollution testing equipment, or new energy technologies that provide public benefit.

To enable this entrepreneurial culture, it is important to have strong, sustained, and enlightened leadership backed by regional and national incentives, and supported where possible by foundations. Indeed in order to attract entrepreneurial faculty and develop a supportive regional ecosystem, the university needs to develop a strategy with a strong focus on innovation and entrepreneurship. Additionally, the public-private partnerships are often necessary for successful innovation.

[90] These include Arizona, Arkansas, Colorado, Florida, Illinois, Indiana, Kansas, Louisiana, Maine, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Montana, New Mexico, New York, Nevada, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, South Dakota, Tennessee, Texas, Utah, Virginia, Washington, Wisconsin, and Wyoming. No information is provided on this site for the university of California system, which is important considering the large role it plays in the research output of the US system. Also in the university of California system institutional funding is mainly tied to student numbers.

[91] Hicks, D. (2011). *Performance-based university research funding systems*. Research Policy.

4. Smart specialisation approaches

Smart specialisation is not a term of art in current use in U.S. policy circles. However, the concepts underlying smart specialisation have been adopted on a de-facto basis in a number of U.S. regions. The development of high-tech clusters has often been organic to a considerable degree, although more recently (2008-16) both federal and state initiatives are now consciously seeking to drive development in promising technology areas that are anchored in regional assets.[92] As noted elsewhere, state-based initiatives are often reflect key elements of the smart specialisation strategy. For example, see the discussion of the New York Nano Cluster below.

4.1 Governance and funding of regional R&I

The federal government under the Obama Administration has launched a series of initiatives based on the concept of regional specialisation, popularized by Michael Porter.[93] For example, the Economic Development Administration is implementing initiatives to establish local proof-of-concept centers to enable innovation-based startups and job creation in green technologies. The Department of Energy has created regional energy-innovation holds to serve as magnets for start-up companies seeking to commercialize innovative green energy technologies. Importantly, the Obama Administration has placed a higher priority on innovation-based manufacturing than any of its predecessors[94]. As discussed above, NIST is overseeing the establishment of the National Network for Manufacturing Innovation (NNMI), geographically-distributed, thematic large-scale centers to facilitate prototyping, pilot production and scale-up support for innovative technologies. These and numerous other Federal programs, large and small, seek to reinforce and support state and local development initiatives and, where gaps in the country's innovation ecosystem exist, to address those gaps with federal programs (e.g., NNMI).

State-based Clusters

Notwithstanding the Federal government's recent activist approach, traditional state and local governments are the source and focus of initiatives to develop and grow regional clusters. A variety of states have undertaken efforts to develop innovation clusters through long-term investments in human capital, scientific infrastructure, and knowledge-based entrepreneurship. For example, many state sectorial policies are focused on promising emerging technologies. Michigan is investing in electric energy storage, Arkansas in wind energy, Kansas in biotechnology, and Ohio in flexible electronics, photovoltaics, and biomedicine. These initiatives have generated substantial investment. The states are building research parks, research institutes within universities able to share common infrastructure, as well as incubators. The states are both competing and learning from each other, and in some cases, learning from foreign countries.[95]

Many of these initiatives have shown considerable promise, even success. Yet in other cases, the regions' investment programs lack critical mass in terms of funding facilities

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[92] For example, Silicon Valley grew without a master plan. That said, the strength of Stanford University and the leadership of the Dean of Engineering, Fred Termen, combined to play a key role in the region's development. Termen envisaged Stanford as a competitor to both MIT and the East Coast electronics industry. The development of the Stanford Research Park, which facilitated the growth of Stanford spinoffs, helped to achieve this goal.

[93] See Porter, M. E. (2011). *Competitive advantage of nations: creating and sustaining superior performance*. Porter argued that in advanced economies, "regional clusters" of related industries are the primary source of competitiveness, export growth, and rising employment and income levels.

[94] For a summary of the Obama Administration's initial efforts and challenges, see National Research Council. Wessner, C. Ed. (2009). *Growing Innovation Clusters for American Prosperity*. National Academies Press.

[95] Wessner, C. W. (2013) *Best Practices in State and Regional Innovation Initiatives*. National Research Council. National Academies Press.

and sustained policy support needed for success. In other cases still, initially successful efforts are compromised by the industrial policies of competitor nations.[96] Companies able to draw on state-backed banks or investments, and benefitting from captive home markets, are able to export low cost products that can rapidly capture market share, to the detriment of regional producers. In other cases, however, some U.S. regions have seen substantial success. Perhaps one of the most noteworthy of these is the nanotechnology center created in upper New York State.[97]

The New York Nanotechnology Initiative

Over almost two decades, the New York state government regional authorities and county development authorities who operated on the pursuit of a vision of a nanotechnology cluster based on semiconductor manufacturing emerging in the State capitol region of Albany, New York[98]. This nanotechnology initiative has fostered the dramatic emergence of a microelectronics manufacturing cluster in the Capital region and is enabling significant developmental efforts in the application of nanotechnology in fields such as medicine, biotechnology and photovoltaics.[99]

The New York nano-effort concentrated public resources on the build out of research infrastructure and expertise at in-state universities, most notably SUNY Albany, leveraging far greater private financial and human resources in the establishment of what is arguably the world's foremost site for industrial applications of nanotechnology. A key institutional innovation was the creation of the College of Nanoscale Science and Engineering (CNSE), recently renamed Albany Polytech.[100] This remarkable industrial cluster is capable of designing and fabricating state-of-the-art semiconductors, which form the core of all of the electronic information technologies.[101] The region is now a global leader in nano-scale manufacturing.

The "Tech Valley" story is not one of an unbroken string of successes, but rather an example of a sustained, broadly-based, bipartisan, public-private effort to reverse long-term regional economic decline and brain drain. Despite numerous obstacles and occasional setbacks, the persistent and collective pursuit of shared long-term goals has resulted in the creation of the world's foremost research infrastructure in nanotechnology and thousands of high-skill, high-wage manufacturing jobs. Federal support, comparatively modest, has proven important at key points in the process. Best practice lessons include:

- Strong leadership at the state and local level and in key universities;

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[96] Wessner, C.W. (2013) *Building the Ohio Innovation Economy.* National Research Council. National Academies Press.

[97] For review of recent state innovation initiatives, see Wessner, C. W. (2013) *Best Practices in State and Regional Innovation Initiatives*. Chapter 2, National Research Council. National Academies Press.

[98] Chernock, J. & Youtie, J. (2013). *State University of New York at Albany Nanotech Complex.* Georgia Tech Enterprise Institute.

[99] For review of the New York efforts, see Wessner, C.W. Ed. (2013). *Building the New York Innovation Economy.* National Research Council. National Academies Press.

[100] Schultz, L. (2011) "Nanotechnology's Triple Helix: A case Study of The University of Albany's College of Nanoscale Science and Engineering,*" Journal of Technology Transfer.* See also: Wessner, C.W. Forthcoming. "Smart Specialisation in the U.S. Context: Lessons from the Growth of the Albany, New York Nanotechnology Cluster".

[101] In 2011 the state of New York and five major semiconductor makers formed the Global 450 Consortium to develop technology for next generation 450 mm semiconductor manufacturing.

- Long-term, sustained commitment of major public and private resources;
- Leveraging of existing regional assets and competencies, including established companies (IBM, GE, National Grid utility);
- Creation of joint public-private research facilities: New York State and IBM jointly invested in the world's only university-based 300mm Semiconductor wafer fabrication facility;
- Timely creation of the sites and infrastructure -- particularly state-of-the-art manufacturing equipment -- necessary to support applied research for advanced manufacturing;
- Emphasis on human resources and skill development, including a focus on "middle skills" by local community colleges, such as Hudson Valley Community College's cooperation with GlobalFoundries;
- Catalytic role played by modest federal research grants/contracts (DARPA, NIST, NSF);
- Broad competency and leadership displayed by regional economic development professionals.

The level of cooperation, the substantial investment in infrastructure, education, and investment packages all contributed to the remarkable growth of the region, including the creation of over 10,000 jobs[102]. The technologies selected were mature, at least with regard to semiconductors, yet it is the world's fastest moving industry, benefitting from large markets and a developed supply chain. A key focus of the cluster is to attract and expand the supply chain needed to support the fabrication of advanced semiconductors – a process that is fully complete.

A key feature of this public private partnership was the funding, expertise, and credibility provided by the contributions of major corporate partners, particularly IBM and its active research programs. These assets, when brought together, helped to drive the growth of the College of Nanoscale Sciences and Engineering (CNSE). They did not ensure the growth of the manufacturing base, but did serve as a point of attraction for a significant number of companies, the Sematech Research Consortium, and ultimately, the GlobalFoundries facility. While not strictly a path-dependent cluster, the regional authorities made effective use of existing assets and created the conditions to attract investments that now total over $13 billion.[103] Collectively, the nano-initiative has attracted investments from 300 companies, accounting for an annual payroll of some $1.4 billion annually as of 2012.[104]

Partnerships for Advanced Manufacturing

The United States economy has grown in no small part as a result of its ability to manufacture goods and sell them in global markets. The manufacturing sector plays an immensely important role in the country's economic growth. Manufactured products lead U.S. exports and employ millions of Americans, as discussed below. In the recent past, it was fashionable among economists to believe that the U.S. economy would be dominated by services, while the loss of market share in manufacturing, as well as decreased manufacturing jobs were "inevitable" for advanced economies. The shock of the 2008 Great Recession and careful analysis by more micro-oriented economists served to underscore the importance of the manufacturing sector[105].

[102] Tech Valley: How it was built and what is needed to sustain it. Georgetown University. Forthcoming.
[103] See Wessner, C.W. (2013). Best Practices in State and Regional Innovation Initiatives. National Research Council. National Academies Press.
[104] Ibid.
[105] National Association of Manufacturers (NAM). (2009). New Data Show United States Is World's Largest Manufacturing Economy But Faces Many Risk Factors. Press release.

Why does Manufacturing Matter?

As these economists and industry groups have pointed out, manufacturing is a key source of employment. Recent research suggests that manufacturing, broadly defined, provides an estimated 18.6 million jobs in the U.S. – about one in six private sector jobs with strong multiplier effects.[106] These jobs are quality jobs that pay a significant premium compared to other sectors of the economy.[107] Manufacturing also has a disproportionate impact on the U.S. innovation system. Manufacturing firms generate 70% of industrial R&D, creating 80% of the patents and employing some 64% of U.S. scientists and engineers. It is also a major

source of growth in trade. U.S. manufacturing generates around $1.7 trillion of value-added each year and is a principal source of U.S. exports. It is also increasingly seen as an essential element in U.S. national security[108]. Accordingly, there is now a growing recognition of the importance of having on-shore production capacity, even in a globalized economy.[109]

Manufacturing is also a key element in the performance of the U.S. innovation system. The manufacturing sector relies on applied research geared towards industrial needs. The incremental improvements frequently required by industry often lead to significant scientific advance.[110] For example, the effort to sustain Moore's Law in the production of semiconductors necessitates advances in basic research as well as cooperative efforts in consortia, such as Sematech, now part of the New York College of Nanoscale Science and Engineering. Similarly, even in global production networks, the importance of regular interactions between corporate research labs and production facilities are increasingly recognized. These iterative interactions also generate synergies allowing for further innovation. In short, U.S. policymakers have over the last decade come to recognize that research, training, investment, and innovation are all linked to and dependent on a dynamic manufacturing base.

In addition to these manifest but neglected contributions, more recent analysis of the service sector shows there is often an intimate link between manufactured products and services, whether its pipeline installation, computer products and services, or aircraft engines, among others. The separation of manufactured products from services is both artificial and inaccurate in that it understates the dynamic relationship between them.

The PCAST Analysis

The Obama Administration issued a series of reports beginning in 2011 through the Office of Science & Technology Policy (OSTP) and the President's Council of Advisors on Science & Technology (PCAST),. The 2011 report was the basis for the launch of the Advanced Manufacturing Partnership (AMP). This is a national effort to bring together universities, industries, and the federal government to identify emerging technologies that could provide domestic manufacturing jobs and enable the U.S. to recapture

[106] For example, traditional estimates of the impact of manufacturing jobs anticipate the creation of two to three additional jobs. Recent experience with semiconductor manufacturing in New York suggests that the ratio for indirect job creation is closer to 5 (actually 4.89) for every direct hire (this estimate is also shared by the European Semiconductor Industry Association). See Tech Valley: How it was built and what is needed to sustain it. Georgetown University. Forthcoming.

[107] Traditional estimates of manufacturing jobs anticipate earnings of some $40,000/yr. However, for high-tech industry such as semiconductor manufacturing in the Albany Tech Valley complex, average salaries are twice that estimate, at over $90,000. Ibid. See also: Bureau of Economic Analysis. (2015).

[108] Wessner, C.W. Ed. (2013). "Rising to the Challenge: U.S. Innovation Policy for the Global Economy". National Research Council.

[109] National Association of Manufacturers (NAM). (2009). New Data Show United States Is World's Largest Manufacturing Economy But Faces Many Risk Factors. Press release.

[110] Modis, T., & Debecker, A. (1988). Innovation in the computer industry. Technological Forecasting and Social Change.

competitive advantage. The initial report identified three pillars to ensure a supportive innovation ecosystem for advanced manufacturing. These pillars focused on 1) enabling innovation 2) the development of the talent pipeline and 3) ensuring a supportive business climate.[111]

A key focus of the report was a recommendation to develop public-private partnerships that would include a national network for manufacturing innovation. The network is to focus on advanced technologies with a potential for high-impact and collaboration that would include technology development, innovation infrastructure, and workforce development. To implement this recommendation, the Administration first reached out in an extensive cooperative effort to ensure active stakeholder engagement on the design and focus of the proposed manufacturing partnerships. The participants included industry, academia, research institutes, economic development agencies, and federal, state, and local governments, among others. The effort involved over 12,000 participants in meetings convened in New York, Ohio, Alabama, California, and Colorado. The key goals of the institutes are to focus on applied research, education and workforce skills, and the development of manufacturing hubs that can serve as industrial commons. As discussed below, the NNMI initiative is to create institutes for manufacturing innovation with common goals, but unique concentrations that will enable industry, academia, and government partners to leverage existing resources, encourage collaboration, and co-invest to accelerate manufacturing innovation and commercialization.

Mission Statement: Combining applied research, education, and workforce skills development

The Federal investment in the National Network for Manufacturing Innovation (NNMI) serves to create an effective manufacturing research infrastructure for U.S. industry and academia to solve industry-relevant problems. The NNMI will consist of linked Institutes for Manufacturing Innovation (IMIs) with common goals, but unique concentrations. In an IMI, industry, academia, and government partners leverage existing resources, collaborate, and co-invest to nurture manufacturing innovation and accelerate commercialization.[112]

As sustainable manufacturing innovation hubs, IMIs will create, showcase, and deploy new capabilities, new products, and new processes that can impact commercial production. They will build workforce skills at all levels and enhance manufacturing capabilities in companies large and small. Institutes will draw together the best talents and capabilities from all the partners to create the proving grounds where innovations flourish and to help advance American domestic manufacturing.[113]

Institute Design

The Institutes are designed to create an "industrial commons," that is a communal space for industry and academia to collaborate. This collaboration is incentivized by the federal government, normally with startup investment between $70-120 million designed to help sustain the Institute over the initial 5-7 years. The Institute consortium owners must be able to provide, at a minimum, a one-to-one co-investment. The structure of the Institute, which reflects a classic Triple Helix concept, is outlined below.

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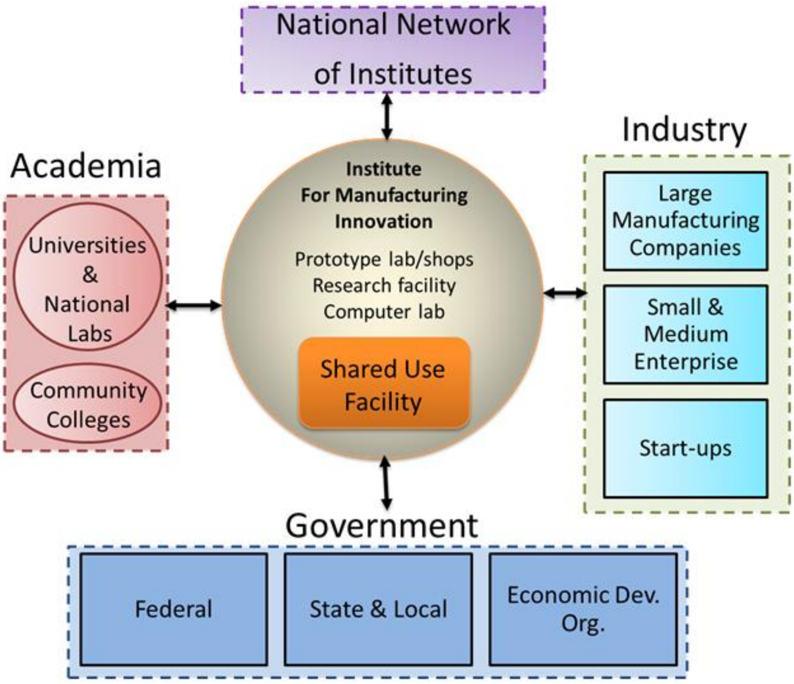
[111] PCAST Report to the President. (2011). Report to the President on Ensuring American Leadership in Advanced Manufacturing. Office of Science and Technology Policy.

[112] See presentation by P. Singerman, NIST Associate Director for Innovation and Industry Services Supporting the Advanced Manufacturing National ProgrammeOffice.

[113] Ibid.

Figure 17 The National Network of Manufacturing Institutes Model



Goals

The overarching goals of the Manufacturing Centers are to accelerate the movement from discovery to application to production by establishing a common space, or an "industrial commons," that would support manufacturing hubs. These would provide an opportunity for partnering between all stakeholders and through collective efforts to help galvanize longer-term investments by industry in infrastructure and next-generation manufacturing techniques. At the same time, these facilities will provide a place to combine cutting edge research with workforce development and training.[114]

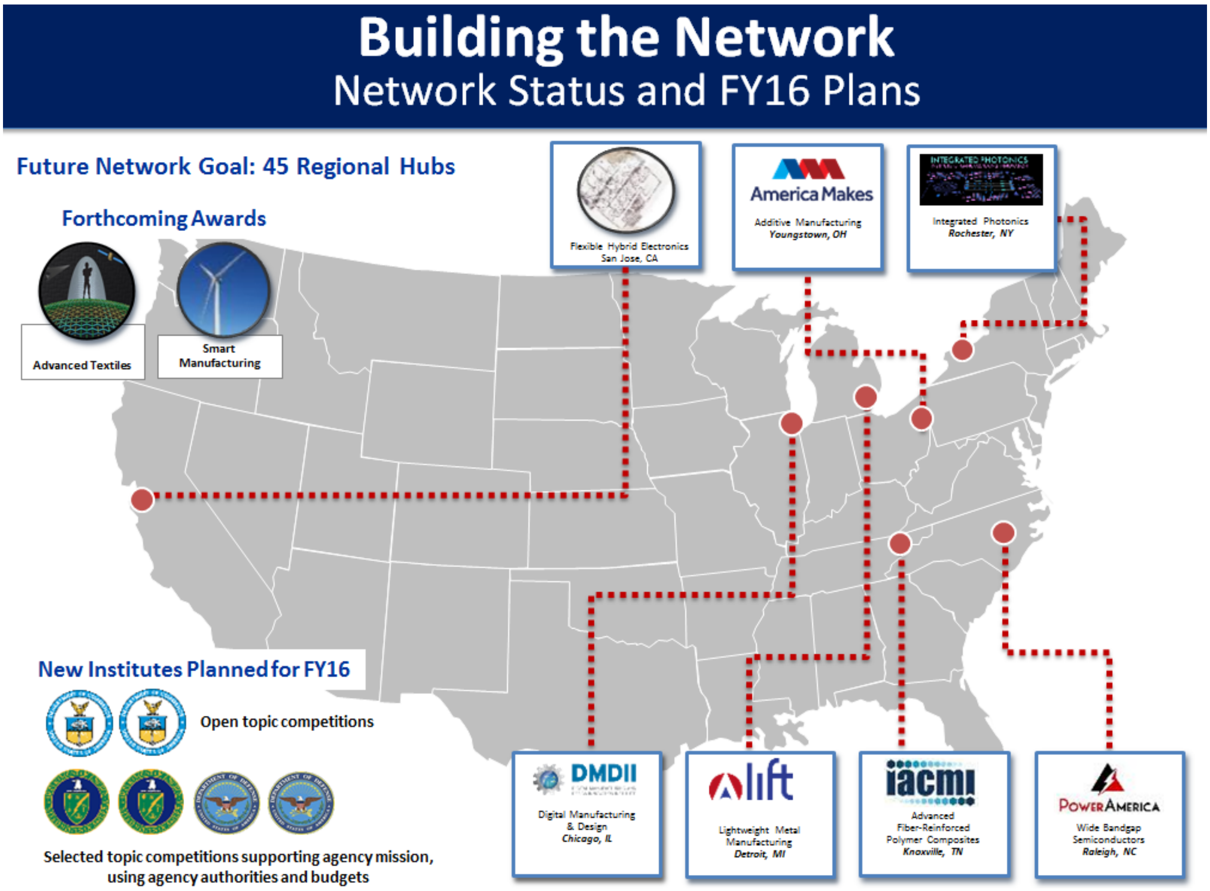
The current network, either in place or planned for 2016, includes centers in the following technological areas:

- **America Makes** – Additive Manufacturing – DoD – Youngstown, OH
- **DMDII –** Digital Manufacturing & Design Innovation – DoD – Chicago, IL
- **LIFT –** Lightweight & Modern Metals – DoD – Detroit, MI
- **PowerAmerica –** Power electronics Manufacturing – DoE – Raleigh, NC
- **IACMI –** Advanced Composites Manufacturing – DoE – Knowxville, TN
- **Integrated Photonics –** DoD – Rochester, NY
- **Flexible Hybrid Electronics –** DoD – Solicitation
- **Smart Manufacturing –** DoE – Solicitation
- **Revolutionary Fibers & Textiles –** DoD – Solicitation

The map below outlines the network status and the plans for 2016.

[114] An outstanding example of this concept is the College of Nanoscale Science and Engineering in Albany, New York, now known as SUNY Polytech.

Figure 18 NNMI Network Status and Planned Developments



Workforce Development: Securing a Talent Pipeline

A core element of the manufacturing strategy is to focus on the challenges of attracting and training the skillsets necessary for advanced manufacturing. Considerable effort was devoted to develop scalable solutions to alter public perceptions of manufacturing, in addition to connecting the educational pipeline with demand-driven training that combines the expertise of community colleges and universities with the actual workforce needs of employers. Again, the mechanism for developing these programs relies on partnerships between manufacturers, academia, and government. The specific goals include:

- A national campaign to change the image of manufacturing
- Programs to provide more manufacturing relevant skills
- Develop a system of nationally-recognized, portable, and stackable skill certifications
- Drawing from models in Germany and Switzerland, develop a U.S.-based apprenticeship model which can generate long-term employment opportunities. A key goal is to reinforce classroom lessons through hands-on learning for which training is paid increased wages as their skills grow.
- Develop online training and accreditation programs eligible to receive federal funds

Improving the Business Climate

AMP recognized that there were policy choices that could be made to affect real change in the manufacturing sector. While many of the initial recommendations were focused on macroeconomic policy, AMP identified early on that there were also specific and targeted policy interventions that could be made to foster the scale-up process in small and mid-sized manufacturers, including both start-ups and established enterprises.

"Scale-up" can be defined as the translation of an innovation into a market. There are significant technical and market risks faced by new manufacturing technologies during scale-up. The path to successful commercialization requires that technologies function well at large scale and that markets develop to accept products produced at scale. It is a time when supply chains must be developed, demand created, and capital deployed. To compete globally and remain a leader in innovation, the United States must significantly improve its ability to translate innovation into practical production.

There are three requirements to achieving commercial scale with promising advanced manufacturing technologies: (1) networked supply chains, (2) rapid diffusion of technology through the networked supply chains, and (3) access to capital. Barriers to achieving scale include the impeded flow of technical or market insights, supply network relationships, and inadequate funding. Small and medium-size manufacturers (SMMs) in the United States are particularly susceptible to information, relationship, and finance barriers. U.S.-based manufacturers of all sizes experience barriers to scaling-up new manufacturing innovations due to financial risk and the capital-intensive nature of production at market scale. Further complicating the scale-up process, support for manufacturing is largely regional and varies substantially across the United States.

Technology Adoption and Scaling

An enduring challenge of innovation policy is to avoid focusing exclusively on technology development with the expectation the take-up of new technologies and subsequent scaling are somehow automatic. For technology to be adopted they have to meet market needs at an affordable cost. Scaling technologies to translate an innovation into the market, encounters both technical and market risks. It's a time where capital requirements are high though markets are not fully developed. It is also a time when supply chains need to be developed, capital deployed, and demand created in order to compete globally. Despite the breadth and depth of U.S. capital markets, capital access for start-ups and established small and medium-sized manufacturers remains challenging.[115]

[115] Reynolds, E. (March 2013). Learning by Building: Complementary Assets and the Migration of Capabilities in U.S. Innovation Firms MIT Report. MIT Industrial Performance Center.

5. Internationalisation of R&I

The United States plays a major role in global science and innovation. Its universities and laboratories are leading sources scientific discovery and innovative technologies. As noted in the section on manufacturing, a major challenge for the U.S. innovation system is its ability to capitalize on these contributions by developing advanced manufacturing capabilities to ensure, that some degree, products developed in the United States can be produced in the United States.

5.1 The U.S. in the global R&D system

The U.S. continues to play a leading role in global science, research, and development. Together, the United States and China account for almost half of the estimated $1.67 trillion in global R&D in 2013. In approximate terms, Japan ranks 3rd at 10% and Germany is 4th at 6%. The next tier of countries includes South Korea, France, Russia, and the United Kingdom each with 2-4% of global R&D. The rising number of researchers and their growing share of the labor force are reflected in the strong growth in R&D expenditures. The estimated global total of R&D expenditures has continued to rise at a significant pace, doubling over the 10-year period between 2003 and 2013.[116] While this growth is a promising development, R&D expenditures vary considerably across countries, with variation in their R&D intensity, their focus on early or later stage R&D, and the degree of their dependency on the business sector for R&D funding.

With regard to R&D intensity, the share of total R&D spending relative to the size of the economy is often used as a convenient indicator of innovative capacity. While useful, this measure has serious limitations. For example, the U.S. ratio has remained around 2.87% of GDP, yet the U.S. invests far more in R&D than any other individual country, even though several smaller economies have greater R&D intensity[117]. Interestingly, Israel and South Korea are essentially tied for the top position, each with ratios of 4.2%. Until recently, Finland was at a similar level.

The use of this percentage of GDP indicator in policymaking has its limitations. Governments have limited control over the size of their economies. Moreover, their ability to rapidly change annual R&D spending is limited politically in most cases, but it is also limited by the absorptive capacity of national innovation systems. Additional funds do not necessarily equal additional quality output. The challenge of achieving a specific R&D-to-GDP ratio is magnified by the fact that businesses tend to be a leading source of R&D funding.[118] In the United States, businesses funded about 61% of all U.S. R&D in 2013. While the corresponding business sector shares are higher, around 75%, in China, Japan, and South Korea and about the same or lower in Germany (66%), France (55%), United Kingdom (47%), and Russia (28%). These differences in allocation complicate the achievement of a specific R&D-to-GDP target while also raising questions as to its policy relevance.

This general measure of R&D intensity is further limited because the nature and objective of national R&D expenditures differ considerably. For example, countries vary significantly in their relative focus on basic research, applied research, and (experimental) development. In 2012, China spent only 5% of its R&D funds, compared to 17% in the United States, on *basic research* — work aimed at gaining comprehensive knowledge or understanding of the subject under study without specific applications in mind. On the other hand, China spent 84% of its R&D funds, compared to 62% in the United States, on *development* — work that is directed toward the *production of useful materials, devices, systems, or methods*, including the design and development of

[116] OECD. (2015). Main Science and Technology Indicators
[117] National Science Board. (2015). NSF Indicators. See section 2.1 for the allocation of U.S. R&D funding by agency and the 2015 proposed increases. This section also discusses the nature and limitations of U.S. R&D defense spending. The measures described here, i.e.
[118] Ibid.

prototypes and processes. The lack of focus on specific applications introduces an element of risk and uncertainty in basic research, as well as posing appropriability issues, which is why a substantial amount of basic research in the United States is funded by the government as a social good.[119] These differences in the allocation of R&D funds are significant, making general comparisons problematic and potentially understating the relative contributions to global science.

5.2 Main features of international cooperation policy

The U.S. is a partner of longstanding with the European Union and its member states, along with most major countries around the globe. The large U.S. R&D enterprise, the mission-driven agencies, the exceptional facilities, the outstanding university system, the scientific excellence, and the relative scale of the U.S. innovation system make the U.S. a key partner for public and private institutions around the world.

From the U.S. perspective, cooperation with major research centers and national research programs provides opportunities to benefit from shared facilities, expertise, and shared costs. Some forms of research, e.g. global warming necessitates offshore research and can often involve shared facilities or equipment, e.g. monitoring water temperature. Combining efforts in cooperative research offers significant benefits for all parties participating in global science while cooperative work on innovative products, such as electric cars, can help develop common standards and platform technologies

U.S. participation in cooperative programs recognizes that modern research as an international enterprise. U.S. science and technology policy fosters cooperation on international research, especially global mega-projects, e.g. climate change. The US uses international science cooperation as a means of fostering good will, reinforcing political relationships, furthering democracy and civil society, and moving the frontiers of knowledge forward.[120]

A primary instrument for US R&D&I cooperation is the bilateral and multilateral science and technology agreement. The US State Department normally takes the lead in negotiating international science and technology cooperation, although the department itself normally does not carry out any research. Recent policy statements note that areas of cooperation include "agricultural and industrial biotechnology research (including research on microorganisms, plant and animal genetic materials, both aquatic and terrestrial), health sciences, marine research, natural products chemistry, environment and energy research."[121] The US participates in a range of forums in the science and technology domain sponsored by OECD, USAID, UNESCO, and other organizations, normally on an ad-hoc basis.

US participation is also frequent in standards-setting activities relating to science and technology through the International Organization for Standardization (ISO). The Association for the Advancement of Science (AAAS) serves as a frequent host organization for science and technology forums held in the U.S. Recent examples include International Symposium on Assessing the Economic Impact of Nanotechnology, as well as joint programs with the EU on commercialization, cluster mapping, and transatlantic R&D collaboration.

The US often participates in large-scale research infrastructure programs. The U.S. has special observer status in the European Organization for Nuclear Research (CERN). The U.S. contributed to accelerator construction costs of CERN's Large Hadron Collider, and has a large number of users because of the uniqueness of the accelerator for particle

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[119] China's more limited focus on basic research may reflect the large business sector role in R&D funding as well as the opportunity to build on basic research done elsewhere (Qui 2014).

[120] One might note that these objectives of US participation do not necessarily focus on the international research cooperation itself. (US Department of State 2012).

[121] Ibid.

physics. The U.S. was a founding partner in the International Space Station through the National Aeronautics and Space Administration. The US participates in the Integrated Ocean Drilling Program (IODP) to investigate seafloor environments through the National Science Foundation, alongside Japan's Ministry of Education, Culture, Sports, Science and Technology; The European Consortium for Ocean Research Drilling; The People's Republic of China Ministry of Science and Technology; the Interim Asian Consortium; the Australian-New Zealand IODP Consortium; and the India Ministry of Earth Science. Various US universities have partnerships in international research infrastructure initiatives. The U.S. has been involved in the Southern African Large Telescope since 2004 through the University of Wisconsin-Madison and other universities (Dartmouth, Rutgers, and University of North Carolina at Chapel Hill) and the American Museum of Natural History (since 2007).

Figure 19 Different Priorities Among Research Leaders

5.2.1 National participation in intergovernmental organizations and schemes and multilateral agreements

The U.S. has Umbrella Science and Technology Agreements that are in force and active or in the final stages of approval with 54 countries or regions.[122] Umbrella agreements exist with the European Union and 15 member countries: Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Poland, Romania, Slovakia, Slovenia, Spain and Sweden. These agreements provide frameworks for science and technology cooperation, intellectual property protection, research access, and related topics but usually do not indicate explicit fields for cooperation. However, a study by Pals and Wang, as part of the Link2US program, indicated that the most common area in these agreements is environmental and climate change (in nine of the agreements), followed by energy and health (in eight agreements), and agriculture and basic research (in seven of the agreements).[123]

[122] US Department of State 2010.

[123] Pals, S. & Wang, T. (2010). *U.S. Science and Technology Cooperation Agreements with Europe: Survey & Analysis*.
American Association for the Advancement of Science.

Implementation of agreements depends on subsequent activity by particular federal agencies and the partner institutions and/or agreements. For example, the National Institutes of Health, the National Science Foundation, and other federal agencies award research grants, R&D contracts, and/or fellowships to researchers from other countries, which includes EU member countries. These awards may be used as instruments for travel to workshops, international comparative research, membership fees in international research organizations, and support for international research facilities and equipment.

Bilateral and multilateral agreements are the main instruments of science and technology diplomacy. These agreements are often driven by the requirements of a summit meeting involving national leadership, or at the request of countries wishing to enhance, or appear to enhance, their collaboration with the U.S. Allocations of grant awards at the country level are a more meaningful reflection of cooperative activity. In turn, they reflect quality of proposals and the level and intensity of cooperation by individual researchers or institutes.

The US has umbrella Science and Technology Agreements with 38 non-EU countries. These include: Algeria, Argentina, Armenia, Australia, Azerbaijan, Bangladesh, Brazil, Chile, China, Columbia, Croatia, Cyprus, Egypt, Estonia, Georgia, India, Japan, Jordan, Kazakhstan, Korea, Libya, Macedonia, Mexico, Morocco, New Zealand, Norway, Pakistan, Philippines, Russia, Saudi Arabia, South Africa, Switzerland, Tunisia, Turkey, Ukraine, Uruguay, Uzbekistan and Vietnam. These agreements typically address areas of research that are priorities for international science and technology agreement with any country – EU or non-EU - such as research cooperation in science and technology in energy, environment, health, agriculture, and basic research. They also characteristically include provisions to address scientific exchange, intellectual property protection and sharing, taxation, and deal with economic development, security, and stability.[124]

5.2.2 Bi-and multilateral agreements with EU countries

The United States of America are a long standing partner of the European Union, with the relations being formalized in 1990 with the adoption of the Transatlantic Declaration. Following the 2007 US-EU Summit, a Declaration on Enhancing Transatlantic Economic Integration and Growth laid the foundation for a growth driven agenda of dialogue. Since then, the Transatlantic Economic Council has become the primary forum for economic dialogue between the EU and the US. On 13 February 2013, the EU and US announced the launch of negotiations on a Transatlantic Trade and Investment Partnership (TTIP). The cooperation between the EU and the US on research and innovation is governed by the Agreement for Scientific and Technological Cooperation, which was originally signed in 1998 and renewed thrice for 5 years each time. In June 2013, the Commission published an independent review of the current agreement[125]. Euratom and USA signed the bilateral cooperation Agreement on fusion energy research in 2001. USA together with Euratom is member of the ITER project. In fission Euratom and USA signed two Technical Exchange and Cooperation Arrangements, one on Nuclear related Technology research and one on Nuclear safety research. Both sides are members of the generation IV International Forum (GIF).

As of February 2014, US entities participated 486 times in FP7 signed grant agreements, receiving a total EU contribution of EUR 76.4 million. This despite the fact that participants from the US (as an industrialized country) did not automatically receive funding from FP7, except in the Health theme of the Cooperation Program. The distribution of the US participation (by total cost of US participants) over the different FP7 subprograms is shown below.

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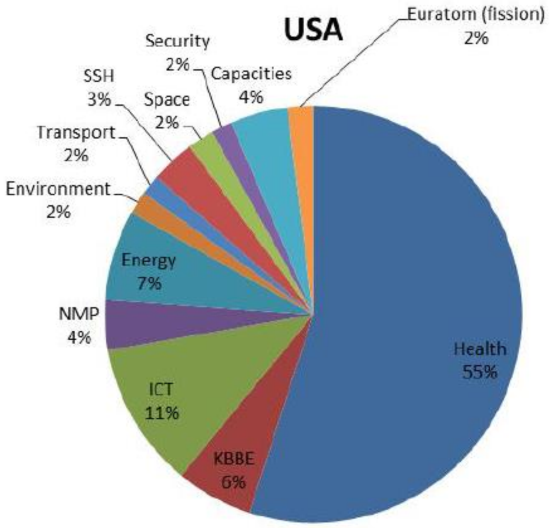
[124] US Department of State 2012.
[125] European Commission. (September 2014). Roadmaps for international cooperation. (62-72).

Figure 20: U.S. Participation Among FP7 Subprograms



5.3 Cooperation with the Horizon 2020 Program Collaboration Options

The USA has also been targeted as an important partner for cooperation in the first Horizon

2020 work program(2014-15), with topics encouraging cooperation with USA researchers included in areas such as marine and artic research (notably to implement the Galway declaration and the Transatlantic Ocean Research Alliance), health research, transport (incl. Aeronautics), materials research, raw materials, ICT, energy research and security research. The EC US Task Force on Biotechnology research aims to promote information exchange and coordination in biotechnology research among programs funded by the European Commission and various US Government funding agencies.

It appears that US Federal Entities still perceive barriers in certain parts of the EU grant agreement for US participation in Horizon2020. During the last Joint S&T Committee meeting between the EU and the US both sides agreed that progress on reciprocal understanding of legal, administrative and financial issues of Horizon 2020 as well as relevant US program was needed. As follow up, a first EU-US workshop was organized in December 2013. The objective was to define a working concept and roadmap helping to bridge the information gap regarding the EU and US funding systems for research and innovation. This process will highlight the main legal aspects of the respective grant systems and should remove barriers for reciprocal participation.

5.4 R&I Linkages between countries in this study

Work is also on-going to strengthen the synergies between the EU's cooperation with the USA and the activities of the Member States (MS), including through the Strategic Forum for International Cooperation (SFIC). This takes place at various levels and a number of prominent examples are:

Marine and Arctic research

The US has enormous research capabilities in marine and arctic research. The National

Oceanic and Atmospheric Administration (NOAA) is the largest organization of that kind in the world with more than a $5 billion annual budget. The US has access to important waters/territories (including arctic) and has just launched its new strategies for oceans84 and arctic. The US is also a major player in the Arctic Council to with the EU has been granted permanent observer status in May 2013. This cooperation will contribute to implementing the EU Blue Growth agenda, the Atlantic Action Plan87 and the Transatlantic Ocean Research Alliance. The priorities of the EU's Integrated Maritime Policy (IMP) and of the Blue Growth strategy feature prominently the Blue Growth call in the first WP2014-2015 of Horizon 2020.

- The Joint Programming Initiative Ocean79 will be a key partner in developing these activities.
- The Seas ERA – NET as well as other marine and arctic related ERA-NETs will strongly be involved in the EU-US information sharing exercise and planned coordination actions.
- The Euro-Basin FP7 projects, the Research Infrastructures Integrated Initiatives INTERACT, Euro-ARGO and EUROFLEETS2

On-going cooperation with the USA on research and innovation also contributes to reaching the objectives of the EU's external policies. In this respect, research and innovation activities contribute to combatting HIV/AIDS, malaria and other diseases and more in general support, reaching international commitments such as the Millennium Development Goals.

Furthermore, research and innovation accompanies the work of the Trans-Atlantic Economic

Council (TEC) or the EU-US Energy Council and it supports the EU's Blue Growth Strategy, the Atlantic Action Plan, the EU Arctic Strategy and the EU-US Aviation Agreements (interoperability, safety).

The general framework conditions for EU-US cooperation are improving continuously over various Framework Programs and the EU and the US have since several years agreed on a reciprocal opening of some program parts such as in the area of health research for example. While cooperation modes tend to become more visible and effective at program level, bottom up project participation is also a strong feature in our cooperation.

Based on the work of the Joint Consultative Group (JCG), established under the EU-US S&T agreement, future cooperation on research and innovation with the USA will address four priority areas:

Health Research

The long lasting strong collaboration between USA and the European Union is proven by the joint collaboration in all the multilateral research initiatives that the EU has either started or joined. Some of them are the International Rare Disease Research Consortium (IRDiRC) and the Global Alliance for Chronic Diseases (GACD). The collaboration is excellent and both USA and the EU have strong capacities and a common vision on how to tackle the most important health problems. As in the past, the joint collaboration between USA and the EU will also represent the central nucleus around which other countries and funding agencies will join. USA is, with the EU, one of the members of the Human Frontier Science Program (HFSP).

USA participants will continue to be eligible to receive EU funding in projects funded through the Horizon 2020 Health challenge, reflecting the reciprocal funding offered to EU participants by the NIH. At the last JCG meeting the possibility for the US to cooperate with the European and Developing Countries Clinical Trials Partnership (EDCTP 2) was also highlighted in addition to the commitment from the Bill & Melinda Gates Foundation. The interoperability aspects in eHealth are also part of the domains included in the scope of EU-US cooperation.

Transportation Research

The main purpose of the EU-US collaboration in transport research is to address global societal challenges and to pursue international standardization requirements. Mutual benefit, joint priority setting, co-funding and critical mass through program level cooperation should be the underlying features. EU-US cooperation in transport research has been growing steadily the last year. The USA and EU signed an Implementing Arrangement at the last JCG meeting (on 12 February 2013), covering Cooperative Activities in the Field of Research, Development, Technology, and Innovation Applied to all Modes of Transport. A steering group has been established to implement the agreement. Cooperation areas include transport infrastructure, traffic management, road safety, urban freight logistics and many others. Synchronized calls for proposals were identified as the preferred cooperation modality, combining focus and flexibility. The joint priority setting is underpinned by a series of joint symposia, organized jointly.

Materials research / Critical Raw Materials / Nano safety and regulatory research

Started in 2011 the EU-US-Japan 3rd Trilateral Conference on Critical Materials hosted in Brussels on May 29-30, 2013 gives future orientation to the EU-US cooperation in this area beside the discussions taking place under the Transatlantic Economic Council – Innovation Action Partnership (TEC-IAP). As follow up to the conference and TEC-IAP, efforts are now being made to involve US partners in forthcoming activities on substitution of critical materials (collaboration is also being pursued in the wider field of computational materials science and materials by design).

Energy research

EU-US cooperation on energy technology research and innovation will continue being promoted under the EU-US Energy Council and its Technology Working Group. Collaboration activities will concentrate along four priority areas: smart grids and energy storage, critical raw materials including for energy, fuel cell and hydrogen and nuclear fusion. Beside these areas included in the EU-US Joint Action Plan 2014-2015, knowledge-sharing and cooperation with the US is also encouraged by the first Horizon 2020 work program in the field of carbon capture and storage and shale gas.

Future and Emerging Technologies research

A common denominator in the discussions with the US has been the need to tackle the paradigm shift in advancing common research endeavors while at the same time keeping in mind the need for transforming research leading to "excellent science" results into tangible economic benefits. The dialogue between EU and US is developing positively especially in the areas of brain research, interoperability of global data infrastructures and digital science policy framework. The EU Human Brain Project (HBP) and the US BRAIN Initiatives are two large-scale research initiatives focusing on the better understanding of the human brain and its diseases with highly complementary approaches. The US is developing new technology to generate brain data leading to a map of the human brain, while the EU is integrating brain data in computer models to simulate the human brain. The data helps build the models and the models help interpret the data.

5.5 Assessment of options for JRC collaborations

The generic nature of this topic makes it difficult to address. Cooperative opportunities are determined by mutual interest in a given topic and comparable assets and expertise. Moreover, the scope and complexity of the innovation system described in this document underscores the need to have specific topics of shared interest, and normally complimentary capabilities. When cooperative efforts are well balanced and mutually beneficial, the case for them can normally be made easily. Cooperation often emerges at the research level in a bottom-up fashion. As described above, the range of cooperative activities between the US and the EU and its member states is extremely broad, reflecting common interest and capabilities.

5.6 Researcher mobility and joint laboratories

Policies to open up national programs to foreign countries are not a priority in U.S. science and technology policy. Barriers to opening up national research programs to participation by non-national individuals primarily lie in visa restrictions. At the country level, Congressional skepticism for funding foreign research can be a major barrier to international cooperation. Additionally, there can also be barriers related to national security policy.

U.S. R&D policy does allow for foreign researchers or research teams to move to the US to perform research, normally on a case-by-case basis. It also allows for foreign researchers or research teams to perform US-funded research in the foreign researchers' home countries. Provisions for these allowances can be found in research program solicitations, which may require a rationale for participation by non-nationals to be submitted along with the research program application. Indeed, the Link2USA program conducted a survey of 11 US federal agencies and found 14 funding programs that were open to EU-based researchers. These programs are in the US Department of Energy, Department of Homeland Security, Department of Transportation, Environmental Protection Agency, National Aeronautics and Space Administration, National Institutes of Health, National Institute of Standards and Technology, National Oceanic and Atmospheric Administration, National Science Foundation, U.S. Department of Agriculture, and U.S. Geological Survey.

5.7 Researchers from abroad and national researchers

Competition for high-quality human capital has become more intense. The United States remains "the destination of choice for the largest number of internationally mobile students worldwide."[126] The absolute number of foreign students enrolled in the U.S. rose from 475,000 in 2000 to 784,000 in 2013. From an international perspective, the U.S. is nonetheless losing market share. Following the 2001 attacks, it became much more difficult for foreign students to enter the United States. Over the last decade, efforts by other countries to attract more foreign students have proved successful. The U.S. share of internationally mobile students fell from 25% in 2000 to 19% in 2013, with substantial shares now held by the United Kingdom, Australia, France, and Germany.

Notwithstanding the difficulties of remaining in the U.S., graduate education in the United States remains particularly attractive to international students. Unlike science and engineering bachelor level degrees, the United States actually awards a larger number of S&E doctorates than China. However, a substantial portion of U.S. S&E doctoral degrees are conferred to international students with temporary visas. In 2013, temporary visa holders, not counting foreign-born students with permanent visas, earned 37% of S&E doctoral degrees.[127] Temporary visa holders are particularly concentrated in engineering, computer sciences, and economics.

As a recent National Science Board report notes, "in 2013, temporary residents earned half or more of the doctoral degrees awarded in these fields. Overall, nearly half of the post-2000 increase in U.S. S&E doctorate production reflects degrees awarded to temporary visa holders, mainly from Asian countries such as China and India. If past trends continue, however, a majority of the S&E doctorate recipients with temporary visas – more than 60% – will remain in the United States for subsequent employment."[128] This represents a significant gain in intellectual capital to the U.S.

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[126] National Science Board. (2016). Science and Engineering Indicators 2016.
[127] National Science Board. (2016). Science & Engineering Indicators 2016. Page 9. Retrieved from http://www.nsf.gov/statistics/2016/nsb20161
[128] Ibid, page 10.

economy. It also entails a major transfer of resources, both intellectual and financial, for the degree-holders who return directly to their country of origin.[129]

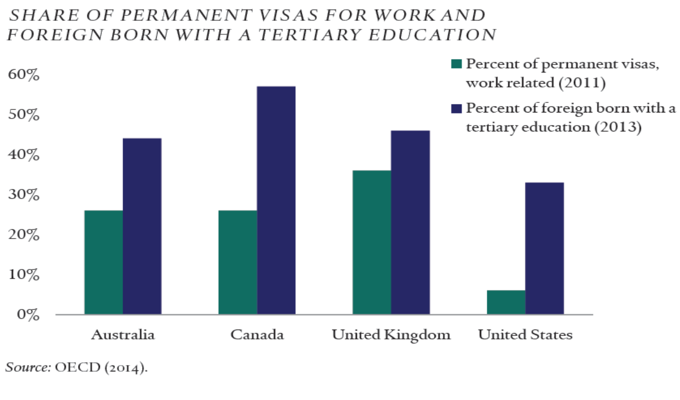
The inability of the United States government to modernize its immigration system is an increasing strain on the effectiveness of the U.S. innovation system. Indeed as one recent report observed, the United States is fortunate to receive much of the world's top talent despite having an immigration system that does not prioritize talent. Under the 1965 Immigration Act – still in force today – roughly two-thirds of permanent immigration visas are allocated to family members but only 15% of visas awarded specifically for employment. Exceptionally talented immigrants, such as lead scientists (and athletes), have their own visa category. But this category remains quite small.

Foreigners who begin college degrees in the United States have up to two years to secure employment, but their stay is not guaranteed. Their employer must apply for a temporary work visa, typically the H-1B, but this visa is capped at 85,000 places annually. This meant that in 2014 the limit was reached within days after it opened. The time required for a potential employee to move from a temporary work visa to a green card can be several years. In the case of Indian and Chinese citizens, who hold the majority of H-1B visas, this can result in backlogs that stretch to a decade or more.

Efforts to move the United States to a point-based system, one which takes into account employment qualifications and employer demand so the most qualified are the most likely to obtain visas, have not been able to move forward due to the current political controversies concerning immigration. Politically, immigration remains extremely contentious, even as net immigration flows across the U.S.-Mexican border have reversed. The lack of a consensus on immigration policy with regard to border security, low-skilled immigration, and the legal status of unauthorized migrants have effectively blocked the U.S.'s ability to import adequate numbers of highly-skilled immigrants, despite their major contributions to the growth of the U.S. economy.[130]

The figure below illustrates this shortfall by highlighting the gap between the percentage of U.S. immigrants who have work-related permanent visas and those who have completed tertiary education

Figure 21 Share of Permanent Visas (2011 – 2013)



129 Even when full tuition is paid by the student, which is frequently not the case, the cost of a doctoral education in the applied sciences normally exceeds the cost of tuition. This is why some leading university presidents argue that when doctoral degrees in STEM education are awarded, they should include a Green Card.

130 Immigrants play a key role in the development of successful startup companies. National Venture Capital Association data on initial public offerings (IPOs) show a sharp increase in economic influence of immigrant founders. Between 2006 and 2012, immigrants started 33% of U.S. venture-backed companies that became publicly traded. Anderson, Stuart. (2013). National Venture Capital Association. *American Made 2.0: How Immigrant Entrepreneurs Continue to Contribute to the U.S. Economy.*
See also Wadhwa, Vivek and Saxenian, AnnaLee and Rissing, Ben A. and Gereffi, G., (4 January 2007). *America's New Immigrant Entrepreneurs: Part I.* Duke Science, Technology & Innovation

5.8 Scope of joint laboratory collaboration in country or in Europe

U.S. and EU member state cooperation is exceptionally broad. It involves multiple departments and agencies on the U.S. side, and an equally broad array of government ministries, agencies, and laboratories on the European side. On the U.S. side, the Department of Defense (DoD) alone has some 600 laboratories (with some 60 large research laboratories)[131]. The laboratory system employs over 100,000 scientists and engineers in support of the nation's war fighting and preparedness missions. The DOD Laboratories establishment ("DoD Labs") as a collective organization is the largest concentration of research personnel employed by the federal government and is responsible for a number of well-known commercial products and many successful military technologies.

There is extensive cooperation between U.S. research agencies and European research agencies, such as the French National Center for Scientific Research (CNRS). The CNRS has an office in Washington D.C. charged with interactions with American and Canadian scientific institutions. The goals are to help increase and strengthen cooperation, identify opportunities for new interactions, and to follow up on existing collaborations. The office helps CNRS researchers to participate in short missions to the United States. In this regard, it carries out a "census" of Franco-American collaboration which shows that over half of French scientists based in the U.S. work in the life sciences, no doubt reflecting the heavy U.S. investments in this domain.

As the CNRS itself describes, the working relationship between French laboratory researchers and their counterparts in the U.S. is both "simple and complex." [132] It is simple in that the most effective cooperation is a result of researchers and laboratories from both sides of the Atlantic wanting to work together. It is important to underscore that this makes for the most effective cooperation. What makes cooperation complex, at least from a CNRS point of view, is that there is no single body that acts as an American equivalent to the French agency. Instead, the country's public research system operates through the cooperative – and sometimes competitive – efforts of more than 20 federal departments and agencies, as well as through the major influence of the relevant congressional committees and the President through the Office of Science and Technology policy. The financial resources allocated to the U.S. departments and agencies are very substantial. For example, during FY15 the Department of Defense received $65.7 billion for their R&D budget, National Institutes of Health received $31.1 billion, the Department of Energy received $12.3 billion, and the National Science Foundation received $5.6 billion, just to name a few of the most well-funded agencies[133].

As a CNRS publication recently noted, in order to better understand the scale of U.S. research budgets, "one simply needs to look at the National Institutes of Health, which has a budget ten times that of the CNRS.[134]" This suggests why the U.S. has a relatively limited need to set up institutions and programs in partnership with other research bodies. At the same time, the NIH and other parts of the U.S. research establishment have long understood that top quality science is increasingly dispersed throughout the world, and Centers of Excellence located in France, the United Kingdom, Germany, and the Scandinavian countries, bring valuable contributions research on global challenges in health, the environment, energy, and security. The difference in scale of effort and the resulting development of the relevant technological ecosystem, e.g. pharmaceuticals, often results in the commercialization of research results within that localized innovation system.

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[131] Aberman, J. (October 2012). Department of Defense Laboratories: Engaging Entrepreneurs in Technology Commercialization. *Amplifier Ventures and TandemNSI.*

[132] CRNS International Magazine. "The science of good relationships".

[133] Office of Management and Budget. The White House. Fiscal Year 15 Agency Allocations.

[134] Ibid

In addition to the joint laboratory cooperation, the U.S. is host to a number of Fraunhofers. Established in 1994, Fraunhofer is a non-profit R&D organization conducting applies R&D for customers from both industry and state/federal government. As a wholly-owned subsidiary of the Fraunhofer Society, it is able to draw on resources, both in the U.S. and in Germany. The stated Fraunhofer goal is to develop and validate scientific applications and technologies for industrial innovation in the U.S. This is carried out in close cooperation with Fraunhofer institutes in Germany in order to provide cutting-edge technologies. The U.S. branch of Fraunhofer also offers unique trans-Atlantic business opportunities.

There are seven Fraunhofer research centers in the U.S. Each research center is affiliated with at least one of the 67 Fraunhofer Institutes in Germany as well as with a major American research university. Current university partners include Michigan State University, Boston University, and the Universities of Maryland, Delaware, and Connecticut.

Fraunhofer research centers currently employ 220 highly-qualified employees (31% hold PhDs and 28% Masters) in the fields of molecular biology, advanced manufacturing, sustainable energy, laser-technologies, coating and diamond electronics, software engineering and energy innovation. The Fraunhofer research centers earned $41 million in contract revenues in 2015. The affiliates have been awarded more than 30 patents

A major area of cooperation is the environment. The United States and Europe enjoy long-standing economic and political relationships, address environmental impacts of joint concern, and face similar opportunities and challenges. By working together to achieve common goals, the U.S. and Europe enhance each region's respective environmental protection efforts while creating a cleaner environment on both continents, and around the world.

Energy cooperation continues to be a primary focus of U.S. bilateral and multilateral cooperation with Europe, at political and technical levels. For example, the EPA provides technical input to bilateral discussions under the Transatlantic Economic Council on energy efficiency and electric vehicles as well as raw materials and nanotechnology[135]. EPA also works closely with Nordic partners within the framework of the Arctic Council to reduce impacts on the Arctic region from short-lived climate forcing pollutants and other contaminants. EPA's energy-related cooperation with the European Commission and key EU member states includes shale gas development, energy efficiency, and methane capture and use.

Shale gas development, especially the process of hydraulic fracturing, is a topic of strong interest to EPA's European partners who hope to learn from U.S. experience as they consider how to approach the development of this resource in their own countries. EPA cooperates with the Department of State's Unconventional Gas Technical Engagement Program, as well as with bilateral partners such as the European Commission, Poland and the United Kingdom to share information and experience on relevant, scientific, policy and regulatory aspects of the issue.

Another area of cooperation comes in the form of the ENERGY STAR program. ENERGY STAR is a joint program of the EPA and DoE which helps citizens save money and protect the environment through the use of energy efficient products and practices[136]. To promote and use the ENERGY STAR label for office equipment throughout Europe, the EPA and the European Union signed an official bilateral Agreement in 2001. This Agreement promotes concrete action on energy efficiency issues, clarifies technical standards for equipment carrying the ENERGY STAR logo, and encourages and facilitates harmonization of test procedures.

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[135] EPA. (2015). EPA Collaboration with Europe. Retrieved from: https://www.epa.gov/international-cooperation/epa-collaboration-europe

[136] Ibid.

An ongoing regulatory cooperation dialogue aims to help reduce risks from toxics in the U.S. and Europe. EPA and its counterparts in the European Commission and the European Chemicals Agency (ECHA) share scientific and technical expertise to enhance the sound management of chemicals. The dialogue also promotes regulatory best practices and information-sharing on areas of mutual interest. A Statement of Intent to enhance this cooperation was signed into place in December 2010. Recent regulatory developments in Europe and the U,S, have made the transatlantic cooperation on chemicals management more important than ever. The U.S. continues to support principles for the reform of the U.S. Toxic Substance Control Act (TSCA) and enhancements to chemicals management in the U.S., while the EU's Registration, Authorization, and Restriction of Chemicals (REACH) program has been in force since 2008[137].

5.9 R&D related FDI

The role of foreign direct investment in the U.S. innovation system is substantial and growing. With the world's largest consumer market, skilled and productive workers, a highly innovative environment, strong legal protections, a predictable regulatory environment, a growing low-cost energy sector, and innovation programs largely open to foreign firms, the United States offers an attractive investment climate[138].

Foreign direct investment in the United States is substantial, with net US assets of foreign affiliates totaling $3.9 trillion. The U.S. continues to be an attractive location for investment with 2012 FDI inflows totaling $166 billion. The investment flows into the US are however somewhat concentrated among a limited number of industrial countries. Seven European countries, along with Japan, Canada, Australia, and South Korea, account for 80% of new FDI. Recent surveys show the U.S. ranked ahead of countries such as China, Brazil, and India as the top perspective destination of foreign direct investment.

The scale of this investment is significant. Value-added by majority owned U.S. affiliates of foreign companies accounted for 4.7% of total U.S. private output in 2011 and employed 5.6 million people, or just over 4% of private sector employment. Much of this investment is concentrated in the manufacturing sector, where about one-third of U.S. jobs of foreign affiliates are located. The share of FDI in manufacturing has recently risen from just under 40% in the last ten years to 45.4% in the last two years, with much of this concentrated in the motor vehicle industry. These affiliates account for 9.6% of U.S. private investment and 15.9% of private U.S. research and development spending.

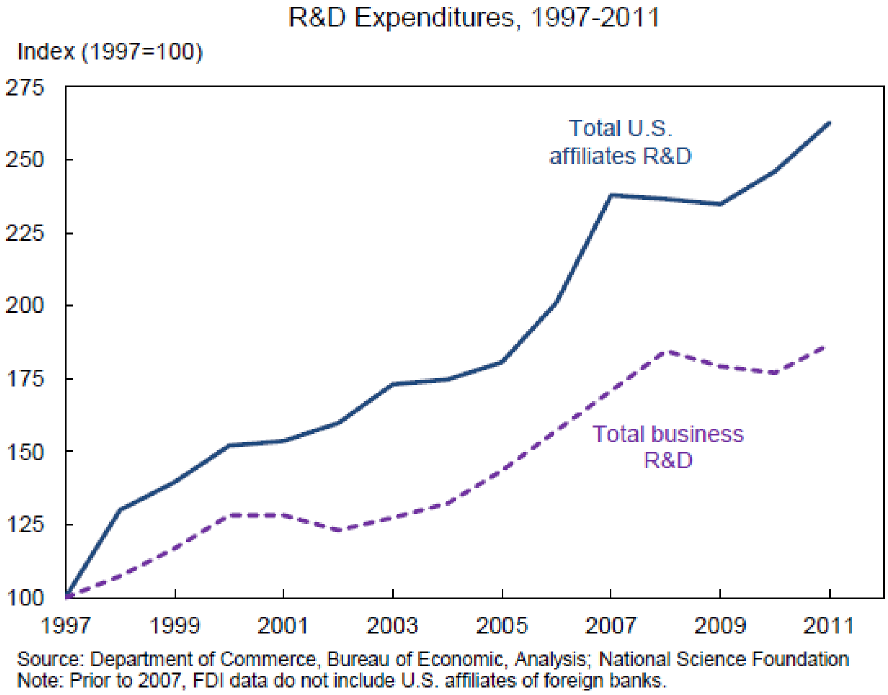
A major positive benefit of foreign owned affiliates is their high research and development spending. The share of foreign firms in U.S. business R&D continues to rise, accounting for $45.2 billion[139]. As the graphic below describes, the growth in foreign owned business spending on R&D has been substantial, increasing 163% since 1997, and double the 87% increase of overall business spending on R&D.

[137] Ibid.

[138] The White House. (October 2013). *Foreign Direct Investment in the United States.*

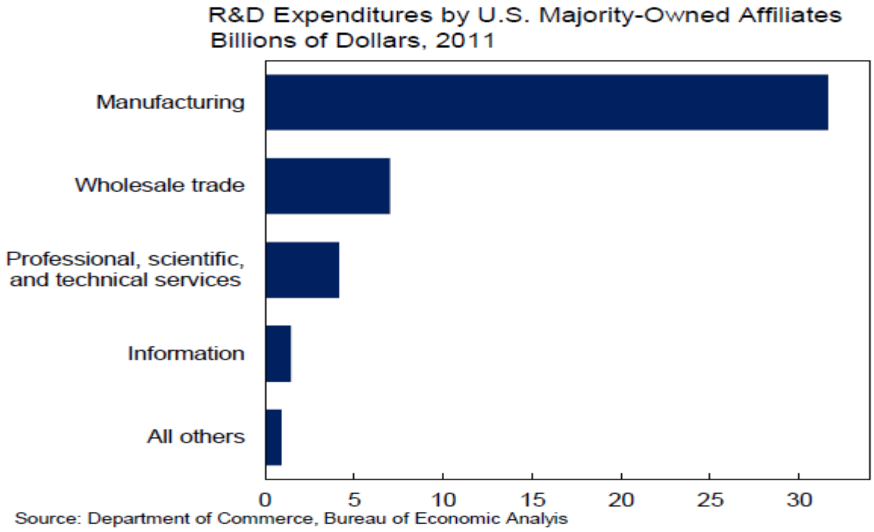
[139] Data on all U.S. business R&D expenditures are available from the National Science Foundation, http://nsf.gov/statistics/industry/

Figure 22 R&D Expenditures (1997 – 2011)



As the graphic below shows, the allocation of these investments by foreign affiliates was concentrated in the manufacturing sector, which accounted for just fewer than 70% of total foreign affiliated R&D expenditures. The wholesale trade sector attracted $7 billion in R&D in 2011, followed by professional, scientific, and technical services at $4.1 billion, and the information sector at $1.5 billion. In sum, the contributions of foreign affiliates represent a very substantial contribution to the U.S. R&D innovation system.

Figure 23 Doctoral Degrees in S&E (2000 – 2013)



6. Challenges to the U.S. Innovation System

In a recent speech to the American Association for the Advancement of Science (AAAS), presidential science advisor Holdren referred to persistent obstacles in U.S. science and innovation. These included inadequate public and private funding of R&D, poor translation of R&D results into practical applications, underrepresentation of women and minorities in STEM fields, underutilization of ST&I talent in federal departments and agencies, and poor policy understanding of the value of basic research and of the ability of science and innovation to address societal challenges.

6.1 Structural challenges of the national R&I system

Notwithstanding the widely recognized contributions of the U.S. university system to innovation, economic growth, and national competitiveness, universities are confronting a variety of challenges with regard to revenue streams, changes in organization, costs of tuition, and shifting relations between research universities, government, and industry. They are also facing more competition from their counterparts overseas. However, for many years U.S. institutions have been able to attract outstanding students and scholars from around the globe who have contributed substantially to our research and innovative capacity,[140] and continue to do so today.

Competition for high-quality human capital has become more intense. The United States remains "the destination of choice for the largest number of internationally mobile students worldwide."[141] The absolute number of foreign students enrolled in the U.S. rose from 475,000 in 2000 to 784,000 in 2013. From an international perspective, the U.S. is nonetheless losing market share. Following the 2001 attacks, it became much more difficult for foreign students to enter the United States. Over the last decade, efforts by other countries to attract more foreign students have proved successful. The U.S. share of internationally mobile students fell from 25% in 2000 to 19% in 2013, with substantial shares now held by the United Kingdom, Australia, France, and Germany.

As a recent National Academy of Sciences report points out, despite their strong performance, U.S. research universities are under stress. They are facing a variety of new challenges that include:[142]

- Long-term declines in federal and state funding – funding per student has declined in public universities by 20% over the last decade;[143]
- Significant underinvestment in campus infrastructure, particularly in cyber-security;
- Significant growth in regulatory burdens through an accumulation of federal and state; regulatory and reporting requirements that are increasing costs;
- The cost of sponsored research is not fully covered by the funders;
- Limited opportunities for young faculty to launch research programs;
- Changing demographic landscape in the United States will require efforts to increase the success of underrepresented students;
- Increasing competition from research institutions abroad that are increasingly well-resourced.[144]

These challenges are real, and as yet unresolved, although the current increases in federal R&D spending should provide much needed additional support for the U.S.

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[140] National Research Council. (2012). Research Universities and the Future of America.
[141] National Science Board. (2016). Science and Engineering Indicators 2016.
[142] National Academies of Science. (2012). Research Universities and the Future of America. National Academies Press.
[143] National Science Board. (2012). Science and Engineering Indicators 2012.
[144] Ibid.

research enterprise and for the institutions that conduct it. However, the growth in regulatory requirements is insidious, costly, and shows little sign of abating. In the longer term, the competitive position of U.S. universities will no doubt remain strong, but their relative competitive position seems destined to shift over time.

Figure 244 Structural challenges to the US R&I system, accompanying policy measures and assessment of their impact

Policy Challenge	**Measures**	**Assessment**
Declining Levels of R&D Investments	Despite continued pressure to reduce non-discretionary spending in the Congress, the December 2015 agreement to substantially increase the R&D budget is a positive step.	Whether this positive trend, and the cooperation it represents, fundamentally depends on the outcome of the 2016 elections. See section 2.2.2 above on R&D funding flows.
Innovation policy	The development of policies and programs to support and enhance U.S. innovation has been a hallmark of the Obama Administration.	The US continues to have a favorable policy environment for innovation, reflected in the innovative strength of US universities, small and large companies, and national labs, buttressed by the sustained support of the federal government and the massive R&D investment by the private sector. The continued flexibility of the labor market in adapting to these new technologies is an additional strength, although one which may be reaching the limits of societal tolerance. The broad range of current Obama Administration innovation policies is comprehensively summarized in the attached annex. See also section 1.3 for R&I policy initiatives.
Education policy	The U.S. university system continues to face major challenges in terms of funding, infrastructure, regulatory burdens, and competition from non-U.S. universities. These institutional issues are compounded by the dramatic rise in student debt.	Despite growing recognition of these challenges, policy responses have been limited. The most positive development has been the 2015 increase in R&D funding, which of course has not yet taken effect. The level to which policy attention can be brought to bear on these issues will depend again on the outcome of the elections and the continued growth of the U.S. economy. Regulatory reforms to address the debt crisis are likely to expand. See section 6.1 above for current challenges to U.S. universities and 5.5 for internationally mobile students.

Manufacturing policy	The current Administration has launched a major initiative in this area. The launch of the new National Network for Manufacturing Institutes (NNMI) is a significant effort designed to develop and refine new methods of manufacturing, and then ensure their dissemination to the broader economy.	The immediate goal is to create a national network of some 15 manufacturing hubs before the end of the Administration, involving approximately $1.2 billion in federal investments to be matched by industry and university contributions. The distributed nature of the effort should provide political anchorage for the program, but network itself is in the formative stage. See section 1.6 for main policy changes in the last five years. See also section 1.4.1 for a new foresight initiative in manufacturing.

6.2 Meeting structural challenges

The United States has a long and successful history of meeting structural challenges over time, with the caveat that the challenges can be recognized as such. As discussed elsewhere in this report, the level of complacency, while eroding, is nonetheless a major impediment to needed investments in infrastructure, education, and research, as well as in the institutions and programs needed to capitalize on them. Indeed, the tradeoff between the focus on reducing government expenditure and debt versus investments in future knowledge and wealth generating capability remains to be resolved, even as there is growing recognition of the need to address global challenges in health, energy, the environment, and security. Perhaps the major challenge in the U.S. is to restore a sense of common purpose and constructive compromise in order to make the government a more effective tool in the service of current and future generations.

6.3 Main lessons and implications for the EU and its Member States

The innovation system of the United States remains the most robust system in the world. Its strengths rely heavily on its university systems, a strong and effective intellectual property regime, multiple mission-oriented research agencies, deep financial markets, and positive framework conditions with regard to labor, bankruptcy, and tax laws. The recent downturn in R&D funding appears to be coming to an end as a result of recent budget agreements. Although that funding remains disproportionately allocated to health research, with a $2 billion increase to the NIH budget, other innovation agencies such as the National Institute of Science and Technology (NIST) received an 11.6% increase and the (previously contested) DoE's ARPA-E received a 5.82% increase. The allocation of substantial funds to the NIST and DoE innovation programs represents a very positive step forward. It remains to be seen if this bipartisan agreement – it is not yet a consensus – will survive the 2016 elections.

Key Challenges

Key challenges include the need to maintain and augment support for the university systems, expand both best practice and financial support in vocational education, increase and sustain support for manufacturing, and generate greater awareness of the nature of global innovation competition, which is increasing in scope and intensity.

Science Funding Is Up

Science agencies received substantial increases in funding. NASA (+ 7.8 %) and DoE Science (+ 5.51%) both went up substantially. The major exception was the NSF, which received a 1.67% increase, bringing its total budget up to $7.4 billion. NSF was nonetheless pleased to see that attempts by some in Congress to determine which areas of science should be funded were removed from the legislation. Importantly, substantial resources have also been allocated to NASA and NOAA to support programs on climate change research.

Focus on Manufacturing

New initiatives, such as the National Network of Manufacturing Institutes (NNMI) have moved ahead rapidly, buoyed by partisan and regional support from both state and industry partners. While the university system retains its global leadership, public funding for universities, particularly at the state level, continues to decline. At the same time as new infusions of funding, global challenges have arisen in cybersecurity, as well as a variety of health challenges ranging from aging to cancer to new diseases such as Ebola and Zika. Last but not least, the upcoming Presidential and Congressional elections pose risk of continuity of commitment, particularly in the area of manufacturing. Similarly, the steady U.S. progress on renewable energy and measures to combat global warming could face discontinuities as the result of upcoming elections, although the growing competitiveness of alternative energy supplies is developing its own momentum.

International Comparisons

In comparing the U.S. innovation system with the efforts of other countries, it is certainly worthwhile to measure the level of relative effort, i.e. R&D as a percentage of GDP. At the same time, it is important to keep in mind the scale and depth of the U.S. research system and its capacity to implement and scale innovative technologies and business practices. International comparisons tend to understate the heterogeneity of the American continent and its 50 states. States such as Massachusetts, New York, Pennsylvania, Maryland, Virginia, Colorado, Washington, and of course, California, would—and do—rank very favorably against many smaller, homogenous economies with high percentage rankings on a small GDP base.[145]

[145] For example, the entire R&D budget of Finland is some two-thirds of DARPA's annual budget. http://www.stat.fi/til/tkker/2015/tkker_2015_2015-02-26_tie_001_en.html

Abbreviations

AAAS – American Association for the Advancement of Science

AMP – Advanced Manufacturing Partnership

ARPA-E – Advanced Research Projects – Energy

AUTM – Association of University Technology Managers

BEA – Bureau of Economic Analysis

BRAIN – Brain Research through Advancing Innovative Neurotechnologies

CNSE – College of Nanoscale Science and Engineering

CRS – Congressional Research Service

DARPA – Defense Advanced Research Projects Agency

DoD – Department of Defense

DoE – Department of Energy

ECHA – European Chemicals Agency

GDP – Gross Domestic Product

HBP – Human Brain Project

I-Corp – the NSF's "Innovation Corps" program

IMI – Institutes for Manufacturing Innovation

NASA – National Aeronautics and Space Administration

NIH – National Institutes of Health

NIST – National Institute of Standards and Technology

NNMI – National Network for Manufacturing Innovation

NRC – National Research Council

NSB – National Science Board

NSF – National Science Foundation

NVCA – National Venture Capital Association

OMB – Office of Management and Budget

OSTP – Office of Science and Technology Policy

PCAST – The President's Council of Advisors on Science and Technology

S&E – Science & Engineering

SBIR – Small Business Innovation Research program

SIA – Semiconductor Industry Association

STEM – Science, Technology, Engineering, and Math

SUNY – Southern University of New York

TEC-IAP – Transatlantic Economic Council – Innovation Action Partnership

VC – Venture Capital

List of Figures

Annex 1 - President's Innovation Report – November 2015

Executive Summary

America has long been a nation of innovators. The United States is the birthplace of the Internet, which today connects three billion people around the world. American scientists and engineers sequenced the human genome, invented the semiconductor, and sent humankind to the moon. And America is not done yet.

For an advanced economy such as the United States, innovation is a wellspring of economic growth. While many countries can grow by adopting existing technologies and business practices, America must continually innovate because our workers and firms are often operating at the technological frontier. Innovation is also a powerful tool for addressing our most pressing challenges as a nation, such as enabling more Americans to lead longer, healthier lives, and accelerating the transition to a low-carbon economy.

Last year, U.S. businesses created jobs faster than at any time since the 1990s. Now is the time to renew our commitment to innovation to drive economic growth and shared prosperity for decades to come. Now is the time for the Federal Government to make the seed investments that will enable the private sector to create the industries and jobs of the future, and to ensure that all Americans are benefiting from the innovation economy.

In 2009, President Obama first issued the *Strategy for American Innovation*, and it was updated in 2011. In this final refresh of the President's Strategy, the Administration has identified additional policies to sustain the innovation ecosystem that will deliver benefits to all Americans.

A Strategy for American Innovation

As the following graphic illustrates, the President's *Strategy for American Innovation* has six key elements. The Strategy recognizes the important role for the Federal Government to invest in the building blocks of innovation, to fuel the engine of private-sector innovation, and to empower a nation of innovators. The Strategy describes how the Obama Administration builds on these important ingredients for innovation through three sets of strategic initiatives that focus on creating quality jobs and lasting economic growth, catalyzing breakthroughs for national priorities, and delivering innovative government with and for the people.

Investing in the Building Blocks of Innovation

The building blocks of the American innovation ecosystem are those areas where Federal investments provide the foundational inputs to the innovation process:

- Making World-Leading Investments in Fundamental Research
  - The President has consistently called for sustaining America's long-term economic competitiveness and growth through robust investments in fundamental research.
- Boosting Access to High-Quality STEM Education
  - The President's plan calls for cultivating the minds of tomorrow's engineers, scientists, and innovators through strong and sustained investment in science, technology, engineering, and mathematics (STEM) education that engage students from all backgrounds and underpin future economic competitiveness.
- Clearing a Path for Immigrants to Help Propel the Innovation Economy
  - Recognizing the disproportionate role of immigrants in building an entrepreneurial society and pioneering world-changing discoveries, the President is helping to clear a path for them to continue making significant contributions to the American economy.
- Building a Leading 21st Century Physical Infrastructure
  - The Administration is committed to making investments in our nation's physical infrastructure that will not only create jobs now but also foster innovation and economic growth for the long term.
- Building a Next-Generation Digital Infrastructure
  - The Administration is committed to sustaining investments to ensure widespread access to broadband and to support the adoption of next-generation digital infrastructure.

Fueling the Engine of Private-Sector Innovation

The Federal Government can empower private-sector innovators by addressing the market failures that stymie innovative activity and by ensuring framework conditions friendly to experimentation and innovation, including:

- Strengthening the Research and Experimentation Tax Credit
    - President Obama has proposed broadening, extending, and making permanent the Research and Experimentation Tax Credit, creating substantial and predictable incentives for U.S. businesses to innovate.
    -
- Supporting Innovative Entrepreneurs
    - To keep America's lead as the best place in the world to start and scale a great enterprise, the Administration is working to ensure all Americans have a fair shot at entrepreneurial success.

- Ensuring the Right Framework Conditions for Innovation
    - The Federal Government can enable a thriving innovation economy by taking steps to ensure that those who strive to introduce new ideas to the marketplace encounter market conditions and rules that facilitate and incentivize their efforts.

- Empowering Innovators with Open Federal Data
    - President Obama has articulated a vision of Federal data as a national asset to be made publicly available wherever possible in order to advance government efficiency, improve accountability, and fuel private-sector innovation, scientific discovery, and economic growth. The Administration has also worked to ensure that more digital data and publications resulting from Federally-funded research are freely accessible to innovators, scientists, and the general public.

- From Lab to Market: Commercializing Federally-Funded Research
    - The Administration's Lab-to-Market Initiative is working to accelerate technology transfer for promising new innovations resulting from Federally-funded research that too often face a slow and uncertain path to commercial viability.

- Supporting the Development of Regional Innovation Ecosystems
    - The Federal Government is playing a critical role in supporting regional efforts to strengthen local and regional innovation ecosystems that sustain economic growth and job creation.

- Helping Innovative American Businesses Compete Abroad
    - The Administration is committed to a trade agenda that has significantly boosted exports, eliminated market-access barriers, and expanded intellectual property protections.

Empowering a Nation of Innovators

The Federal Government can help empower more Americans to be innovators:

- Harnessing the Creativity of the American People through Incentive Prizes
    - The Administration will continue to build on the important steps the Federal Government has taken to make incentive prizes a standard tool in every agency's toolbox.

- Tapping the Talents of Innovators through Making, Crowdsourcing, and Citizen Science
    - The Federal Government is finding new paths to tap the ingenuity of the public to address real-world problems, while also engaging more students in STEM learning and entrepreneurship. These efforts include making, crowdsourcing, and citizen science, among other initiatives.

Creating Quality Jobs and Lasting Economic Growth

Technological innovation is the key source of economic growth for the United States. Coordinated Federal efforts can have large impacts on jobs and economic growth in the following priority areas:

- Sharpening America's Edge in Advanced Manufacturing
  - Leading in manufacturing will strengthen America's edge in both traditional and high-tech products, and ensure that if it is invented in the United States, it can be made in the United States. The Administration will launch new efforts to support manufacturing startups and to increase the innovative potential of America's small manufacturers and manufacturing supply chains. The Administration has also set a goal of creating a network of 45 Manufacturing Innovation Institutes within ten years, and has already provided funding for ten.

- Investing in the Industries of the Future
  - Emerging technologies today promise to enable a wide range of transformative products with broad economic impact, just like path-breaking innovations of the past, such as the steam engine and the Internet, transformed the U.S. economy in earlier times. The President is committed to investing in these emerging technologies.

- Building an Inclusive Innovation Economy
  - The Administration is taking action to ensure that Americans from all backgrounds can participate in the 21st century innovation economy.

Catalyzing Breakthroughs for National Priorities

Maximizing the impact of innovation on national priorities means identifying those areas where focused investment can achieve transformative results to meet the challenges facing our nation and the world:

- Tackling Grand Challenges
  - The Administration is supporting targeted efforts to meet Grand Challenges, which are ambitious but achievable goals that harness science, technology, and innovation to solve important national or global problems and that have the potential to capture the public's imagination.

- Targeting Disease with Precision Medicine
  - The Administration is investing in a Precision Medicine Initiative to understand better the complex mechanisms underlying a patient's health, disease, or condition, and to predict better which treatments will be most effective.

- Accelerating the Development of New Neurotechnologies through the BRAIN Initiative
  - The BRAIN Initiative is developing new technologies that will enable a deeper understanding of brain functions, improving the ability of researchers and physicians to diagnose, treat, and prevent diseases of the brain. The BRAIN Initiative could also lead to breakthroughs in computing that are inspired by human perception and cognition.

- Driving Breakthrough Innovations in Health Care
  - Innovations in health care delivery, growing from collaboration across purchasers, providers, and patients, promise to help improve quality of care, prevent medical errors, and reduce costs. Through the Center for Medicare and Medicaid Innovation, the Administration is testing new care delivery models that seek to deliver the same or better care at significantly lower cost.

- Dramatically Reducing Fatalities with Advanced Vehicles

  - Accelerating the development and deployment of advanced vehicle technologies could save thousands of lives annually. The Administration is launching new efforts to accelerate the path to deployment for these promising technologies.

- Building Smart Cities
  - Making our cities "smarter" means equipping them with the tools to address the pressing problems that their citizens care most about. The Administration has launched a new research and deployment initiative that will invest over $160 million in Federal research and leverage the efforts of a broad network of cities, universities, companies, and nonprofits to achieve real results, such as urban traffic management systems that can reduce commuting times by 25 percent or more.

- Promoting Clean Energy Technologies and Advancing Energy Efficiency
  - The Federal Government is investing in technologies to enable the development of renewable and other clean energy sources, make energy go further through energy efficiency, and reduce carbon pollution, while helping to improve America's energy security.

- Delivering a Revolution in Educational Technology
  - With the technological conditions ripe for the development of advanced educational technologies that can transform teaching and learning, the Federal Government is making critical investments in the development of next-generation educational software.

- Developing Breakthrough Space Capabilities
  - The Federal Government is developing new space technologies and leveraging partnerships with the private sector to dramatically lower the cost of accessing and operating in space, while enabling ambitious new missions. Such technologies are helping to create a burgeoning U.S. private space sector.

- Pursuing New Frontiers in Computing
  - Guided by the recently launched National Strategic Computing Initiative, Federal departments and agencies will work together to advance the state of high-performance computing in order to drive economic competitiveness, scientific discovery, and innovation.

- Harnessing Innovation to End Extreme Global Poverty by 2030
  - The Administration is advancing a new model of development grounded in evidence-based evaluation, rapid iteration, country engagement, and partnership that catalyzes talent and innovation everywhere to accelerate efforts to end extreme poverty by 2030.

Delivering Innovative Government with and for the People

With the right combination of talent, innovative thinking, and technological tools, government can deliver better results with and for the American people:

- Adopting an Innovation Toolkit for Public-Sector Problem-Solving
  - The Administration is creating an "Innovation Toolkit" that will increase the ability of agencies to deliver better results at lower costs for the American people. These approaches can increase the effectiveness and agility of the government through improvements in its core processes and ability to solve problems.

- Fostering a Culture of Innovation through Innovation Labs at Federal Agencies

- A network of Innovation Labs can foster a culture of innovation at Federal agencies by empowering and equipping agency employees and members of the public to implement their promising ideas to more effectively serve the American people.

- Providing Better Government for the American People through More Effective Digital Service Delivery
    - It should be as easy and intuitive for American citizens and businesses to engage with government services online as it is for them to conduct online transactions with the most IT-savvy businesses. The Administration is creating U.S. Digital Service teams across government to speed the adoption of private-sector best practices for designing, building, and deploying easy-to-use online services.

- Building and Using Evidence to Drive Social Innovation
    - The Administration is committed to improving our ability to solve societal problems by using evidence about "what works" where it exists and developing it where it does not. The Administration is also using Pay-For-Success approaches to pay for outcomes as opposed to inputs, and to scale-up evidence-based interventions.

Annex 2 - SIA Roadmapping

Semiconductor Roadmapping

Technology roadmaps are strategic tools for planning resource allocation and identifying research needs and challenges in evolving technologies over a relatively long time horizon. The most successful roadmaps are developed and refined by collaborating stakeholding private, public and academic organizations which have a role in carrying out tasks identified during the roadmapping process. Roadmapping and technology forecasting were used by U.S. military planners in and after World War II in areas such as atomic power, missile defense and aviation, and spread to the semiconductor industry, with individual U.S. companies beginning to adopt the practice internally by mid-1970s. In the U.S. semiconductor industry, roadmaps have featured technology targets to be reached by specific dates based on parameters such as process feature size and device capability and density.

The first industry-wide technology roadmapping in semiconductors took place in the Very High Speed Integrated Circuit (VHSIC) program, an Army/Navy/Air Force project launched in 1980 with industry participants to develop devices with military applications based on silicon technologies. VHSIC arose during the Cold War out of a perceived crisis, when numerically-superior Soviet Bloc forces confronted NATO in Europe. VHSIC involved large scale commitment of resources (roughly $1 billion) and collaboration between numerous public and private organizations, with a government sponsor pushing very long range objectives. One study observes that VHSIC's

> *biggest contribution was that it forced the relatively young semiconductor industry to look ahead in a fashion that was not yet familiar to them…. [I]t was the close collaboration with industry that allowed the VHSIC program office to set the process technology targets that would serve as the basis not only for this program, but subsequent industry roadmapping efforts.*[146]

The necessity of industry roadmapping was increasingly evident during the 1980s as the semiconductor manufacturing process became more complex and automated. Manufacturers needed to integrate large numbers of sophisticated machines, materials and processes which were being developed by different vendors, in real time. This could not be done without coordination among stakeholders establishing clearly-defined technology requirements, metrics, and developmental timelines.

The Semiconductor Research Corporation (SRC), a government-supported research consortium formed by the Semiconductor Industry Association in 1983 to support university-based R&D, introduced the first industry-wide goal-setting technology "roadmap" in 1984-85, a protocol of 10-year research targets intended to organize university research in a coherent manner to address anticipated technological challenges. Larry Sumney, who had served as program director of VHSIC and went on to head SRC, observed in 2011 that SRC brings together the relevant industry players with universities and government. The industry sectors lead by identifying the most urgent R&D needs at the precompetitive level, and the government provides incentives by co-funding the relevant research in universities. "Given the diversity of participants, this ecosystem can be distributed, but very coordinated. We see a flow of related ideas and technologies moving in both directions between industry and academia, with government playing

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[146] Robert B. Schaller, Technological Innovation in the Semiconductor Industry: A Case Study of the International Technology Roadmap for Semiconductor (2004), p. 418.

an important role."[147] SRC developed and refined semiconductor roadmaps through the 1980s in annual "summer studies"--informal two to three day off-site gatherings of company representatives with technical expertise--that roughed out long range goals, giving direction and focus to university research.

Sematech was established in 1987-88 (with SRC head Larry Sumney serving initially as Executive Director) as a government/industry funded consortium to pursue research in semiconductor manufacturing technology. Sematech utilized roadmapping even before it was formally established, convening industry-government-university workshops which broke down barriers between organizations, defined the future technological needs of the industry and identified potentially "show-stopping" technological challenges to enable resources to be mobilized to address them.[148] The planning workshops involved scientists and engineers from companies, the government and SRC divided into groups of 10-15 people according to particular technology themes, with some groups overlapping with related workshops.

The workshops were a venue for sharing ideas and helped participating companies understand shared technical problems as well as what was expected of them individually.

The Sematech workshops also had the effect of leveraging large investments by industry players. Sam Hurrell, one of the founders of Sematech and a participant in the roadmapping process, recalled later that:

> *Those were working sessions which drove to some conclusion about the needs and requirements of the industry and what [were the] most likely alternatives to meet those needs and requirements. Those were very powerful interactions that had never been able to happen before…. Sematech's [proposed] $100 million from the government and $100 million from industry was peanuts compared to what the industry spends on its own balance sheets. Suppliers alone spend $1.4 billion a year on RD&T [research, development, and testing]. The member companies spend $6 to $7 billion a year on RDT&E [evaluation] on a comparable basis. What the strategic workshop road maps did was to set in motion a bunch of focusing activities of $8 and $9 billion worth of effort, not just $200 million worth of effort*.[149]

Turner Hasty of Texas Instruments, who served in several posts at Sematech including CEO, observed in 2000 that the early roadmapping workshops were critical for several reasons. They established concrete technological targets that gave immediate focus to company research efforts and reduced risk. Roadmapping enabled companies to work together in a non-threatening way to achieve shared goals, establishing the basis for future collaboration--"they turned a chaotic

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[147] Larry Sumney "Semiconductor Research Corporation," in National Research Council, C. Wessner, ed., *The Future of Photovoltaic Manufacturing in the United States* (Washington, D.C.: The National Academies Press, 2011), p. 188.

[148] Paolo Gargini of Intel, a participant in semiconductor roadmapping during the 1990s, said in a 2011 oral history interview that "in the 1997 roadmap for the first time, for instance, I had the idea that by the middle of the next decade, 2004/5/6, we had to introduce high-k metal gate. And at the end of the meeting, especially the university people were terrorized, because they thought they were not going to think about it until 2010. At that point, this was in '97 … in the next six years you have to be ready, so and it was really a terror for all of them all of a sudden, something that was really a low key project, all of a sudden was becoming very important. The benefit of it was that indeed, fortunately for all of us, many of the universities began working on it…." "Oral History of Paolo Gargini," July 27, 2011, Mountain View, California (Computer History Museum, 2011).

[149] Larry D. Browning and Judy C. Shetler, *Sematech: Saving the U.S. Semiconductor Industry* (College Station, TX: Texas A&M University Press, 2000), p. 42.

situation into working as a team." Finally, they helped develop broader national support--by embracing DoD, DoE and universities, all players "got their say… The workshops were amazingly successful in getting a national voice."[150]

The National Advisory Committee on Semiconductor (NACS) was established by Congress in 1988 at the suggestion of SRC to develop a national semiconductor strategy with the specific goal of achieving a 0.12 micron manufacturing process by the year 2000. Committee members included representatives of IBM, Applied Materials, Intel and other companies, the White House Office of Science and Technology Policy, NSF, DoD, DoE, and DoC. The effort began with a large workshop, Micro-Tech 2000, convening the players to establish a roadmap to achieve the goal which used the Micro Tech 2000 roadmap as a "foundation to build a single set of roadmaps that use the talents of the expert participants to anticipate the needed technological developments…"[151] NACS asked the Semiconductor Industry Association to implement the Micro Tech 2000 roadmap. SIA convened a series of workshops in and after 1992 setting detailed technological objectives over a 15-year timetable.[152] The results were published and made available worldwide for free in 1993.

In 1998 SIA collaborated with counterpart organizations in Japan, Europe, Korea and Taiwan to create the first global semiconductor roadmap, the International Technology Roadmap for Semiconductors (ITRS), which is developed and adjusted in thematic Technical Working Groups (TWGs). Annual refinement of the ITRs has become routine for the global semiconductor industry, its suppliers, and relevant government and university organizations. Participants remain heavily US-based and include representatives of industry, academia and government.[153]

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150 Schaller (2004) pp. 460-461.
151 Semiconductor Industry Association, *Semiconductor Technology Workshop Conclusions* (1993), cited in Schaller (2004) op. cit. p. 491.
152 Robert M. Burger, *Cooperative Research: The New Paradigm* (SRC, 2011).
153 See ITRS Reports, <http://www.itrs2.net/itrs-reports.html>.

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JRC Mission

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

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