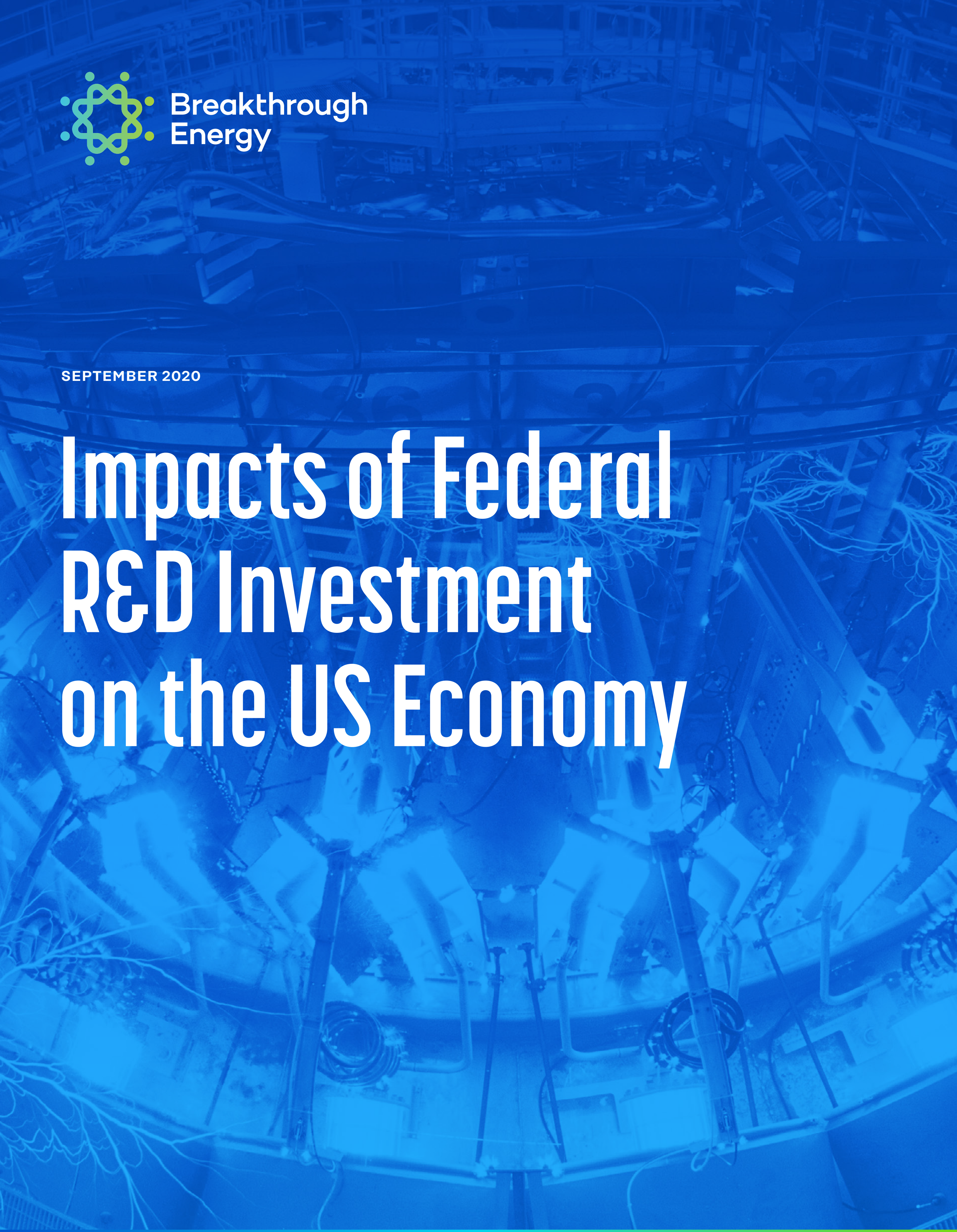

Breakthrough
Energy

SEPTEMBER 2020

Impacts of Federal R&D Investment on the US Economy

A Word from Breakthrough Energy

Breakthrough Energy believes everyone should have access to clean, reliable, and affordable energy — both to ensure our communities can thrive today and to avert a climate change disaster in the future. Rapid technological change is the key to accomplishing that goal.

We need new ways to power the globe, build buildings, move around, produce food, and make critical materials like cement and steel that don't emit greenhouse gases. The only way we will be successful in that effort is through increasing the amount of research and development (R&D) that goes into the technologies that will drive our economy in the future.

We already know how valuable R&D dollars — both government and private-sector funded — are to long term economic vitality and America's ability to lead the world with the industries and companies that will power this change. But there has not been a great deal of analysis on the impact of those R&D dollars on local economic activity today.

Given the previous dearth of research on this topic, we commissioned PricewaterhouseCoopers LLP to evaluate the impact of government investment in defense, health, and energy R&D on the American economy, an analysis that is particularly critical as the nation continues to find the most effective ways to recover from the ongoing global COVID-19 pandemic and related economic crisis.[1]

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[1] The report analyzes the impact on the economy in terms of jobs, labor income, contribution to GDP and taxes of federally funded R&D, including for defense, health and energy, without regard to the specific research projects funded within each sector.

The results paint a compelling picture of how federally-funded defense, health, and energy R&D support our economy and workforce.

- While the greatest value of R&D is realized over the long term, federal funding in the health, energy, and defense sectors have a tangible benefit for the economy and jobs today. In 2018, public R&D investment directly and indirectly supported more than 1.6 million U.S. jobs, $126 billion in labor income, $197 billion in added economic value, and $39 billion in federal and state tax revenue. The 446,000 direct jobs across the United States provided by public R&D investment are good paying jobs, with average compensation 83% higher than that in the overall economy in 2018.
- If the nation increased R&D spending to 1% of GDP by 2030 (approximately $315 billion annually), that investment would support 3.4 million U.S. jobs and add $301 billion in labor income, $478 billion in economic value, and $81 billion in tax revenue.
- R&D investment also provides long-term societal benefits by spurring productivity, invention, and patenting activity. These investments today have the potential to significantly improve human life by making a down payment on addressing challenges as expansive as climate change and pervasive as Alzheimer's and cancer.

The findings of this study send a clear message about the impact of federal funding for R&D. Unfortunately, we are falling behind on developing the clean energy technologies we need to get to net-zero greenhouse gas emissions by mid-century. Fully 75% of the clean technologies we need to reach midcentury climate goals are still in the early stages of development, according to the IEA's Special Report on Clean Energy Innovation.

We know we can create jobs today, make a down payment on America's long-term economic health and competitiveness, and position ourselves to address the greatest challenges of our time – if we commit to investing substantial public resources in R&D. We encourage leaders and policymakers to consider ways to increase R&D investment to support the rebuilding of our economy in the short term and lay the foundation for a stronger economy in the years to come.

> "If we want to avoid a climate disaster, we need a technological transformation on a scale and at a speed we haven't yet seen. That's going to take governments, researchers, public and private institutions working together and investing in the innovations we need to achieve net-zero greenhouse gas emissions.
>
> When it comes to R&D, it's hard to overstate the importance of public investment.
>
> Government funding is especially important to ensure scientists have the space and the freedom they need to test out bold new ideas and keep working on the ones that have the most promise for the future. That kind of risk-tolerant commitment is how we developed lifesaving vaccines and disease treatments, made revolutionary breakthroughs like the information technology that led to the Internet, and what put people on the moon more than 50 years ago.
>
> We've always known the value of R&D in creating the technologies that the future economy will rely on. This report makes clear that there is also tremendous impact right now. By significantly increasing our commitment to R&D for the new technologies that will power the planet while helping to avoid a climate disaster, we can make sure the United States continues to lead the world in building the industries of the future while sparking much needed economic activity today."
>
> **BILL GATES**
> *Founder, Breakthrough Energy*

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Impacts of Federal R&D Investment on the US Economy

September 2020

Prepared for

Breakthrough Energy

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Impacts of Federal R&D Investment on the US Economy

Executive Summary

Investment in research and development (R&D) contributes to national economic growth in the short run through job creation and income gains and in the long run through the generation of knowledge, skills, and technological improvements that enhance the productivity of workers both inside and outside the organization doing the research. In addition, R&D contributes to advancements that enhance human health, strengthen national security, and protect the environment. While the private sector funds and performs most R&D in the United States, the public sector (primarily the federal government) plays a vital role in funding R&D, especially early-stage basic and applied research, that would not otherwise occur due to the inability of private entities to fully capture the economic benefits of their investments.

Breakthrough Energy engaged PwC to assess the short- and long-term economic impacts of public R&D investment in the United States, with a focus on federal R&D investment in the defense, energy, and health sectors. This report provides a review of recent findings on the economic contributions of public R&D investments and presents new estimates of the national and state-level short-run economic impacts of federal R&D funding by sector in terms of employment, labor income, value added, and tax payments.[1]

Any single R&D investment can be viewed as a risky investment, with an uncertain return given the nature of exploratory research. However, viewed as a portfolio of investments, the historical track record suggests that current investments in R&D by the federal government are likely, on average, to lead over the longer run to important technological advancements that improve productivity, strengthen US economic competitiveness, and enhance human life and well-being. As examples, federally funded R&D contributed to the development of radar, jet propulsion, electronic computing, GPS, the internet, hydraulic fracturing technology, lithium-ion batteries, anti-retroviral drugs for the treatment of HIV, the Human Genome Project, and multiple vaccines.

Empirical estimates indicate that today's investments in R&D by the federal government can be expected to lead to long-term increases in patenting and associated manufacturing employment. Research on the impact of NIH funding on patenting indicates that current levels of NIH funding ($32 billion in federal outlays in fiscal year 2018) may lead to approximately 8,600 patents, which are associated with roughly 22 FDA-approved drugs and $75 billion in subsequent drug sales.[2] While the long-term benefits of medical innovation are difficult to value,

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[1] Value added refers to the additional value created at a particular stage of production; the sum of all value added in the US is gross domestic product ("GDP"). Value added consists of: employee compensation, proprietors' income, income to capital owners from property, and indirect business taxes (including excise taxes, property taxes, fees, licenses, and sales taxes paid by businesses).

[2] Pierre Azoulay, Joshua Graff Zivin, Danielle Li, and Bhaven Sampat, "Public R&D Investments and Private-sector Patenting: Evidence from NIH Funding Rules," *Review of Economic Studies*, Vol. 86, pp. 117-152, 2019; National Science Foundation, *Survey of Federal Funds for Research and Development: Fiscal Years 2018-19,* Table 3, January 2020, available at https://ncsesdata.nsf.gov/fedfunds/2018/.

one study found that the typical new drug approved by the FDA saves over 11,000 life-years annually.[3]

Rather than crowding out private investment, studies have found that federal R&D has a crowd in effect. Estimates from one study imply that current federal R&D investment in the defense sector of $58 billion in 2018 results in approximately $52 billion in additional private sector R&D investment.[4] The increased private sector R&D brings with it an increase in private sector employment and productivity. In terms of impacts on entrepreneurship, research indicates that federal R&D investment through the Small Business Innovation Research (SBIR) program improves the long-term viability and success of innovative startups, e.g., in terms of revenue growth and innovative productivity, particularly for firms focused on developing clean energy technologies.[5]

This report quantifies the short-run economic impacts of federal R&D investment as of 2018 and under a potential future trajectory of increased federal R&D investment from 2021 through 2030.[6] The analysis accounts for the direct impacts from R&D performers, the indirect impacts resulting from the supply chain to R&D performers, and the induced impacts resulting from expenditures of labor income earned by employees of R&D performers and their supply chain.

> *"Including direct, indirect, and induced effects from operational and capital spending, federal R&D investment supported 1.6 million jobs, $125.5 billion of labor income, $196.7 billion in value added, and $38.9 billion in tax payments in 2018."*

In 2018, federal funding of $131 billion for R&D investment directly provided 445,800 jobs for American workers, paid $50.9 billion in wages, salaries and fringe benefits and proprietors' income, and generated $70.6 billion in GDP and $13.0 billion in tax payments to federal, state, and local governments (see **Table E-1**). Including direct, indirect, and induced effects from operational and capital spending, federal R&D investment supported 1.6 million jobs, $125.5 billion of labor income, $196.7 billion in value added, and $38.9 billion in tax payments in 2018. The economic multiplier for employment is 3.7, meaning that, for each direct job generated by federal R&D investment, another 2.7 jobs are supported throughout the rest of the economy.

> *"For federally funded R&D jobs, average compensation per direct job is about $114,000 in 2018 – 83 percent higher than the overall economy average compensation of about $62,000."*

The employment generated by federal R&D investment pays higher wages than the average job in the US economy. For federally funded R&D jobs, average compensation per direct job is about $114,000 in 2018 – 83 percent higher than the overall economy average compensation of about $62,000. Federally funded R&D direct jobs include

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[3] Frank Lichtenberg, "Pharmaceutical Innovation, Mortality Reduction, and Economic Growth," in Murphy and Topel, eds., *Measuring the Gains from Medical Research*, 2003.

[4] Enrico Moretti, Claudia Steinwender, and John Van Reenen, "The Intellectual Spoils of War? Defense R&D, Productivity and International Spillovers," NBER Working paper No. 26483, November 2019.

[5] Sabrina Howell, "Financing Innovation: Evidence from R&D Grants," *American Economic Review*, Vol. 107(4), pp. 1136-64, April 2017.

[6] Short-run impacts were calculated using the IMPLAN model, an input-output model based on government data.

highly compensated researchers, scientists, and managers as well as many lesser compensated occupations, e.g., in lab maintenance and supply. Including direct, indirect, and induced employment in sectors ranging from agriculture to manufacturing to retail, average labor income per federally funded R&D job is about $77,000, or 24 percent higher than the average for the overall economy.

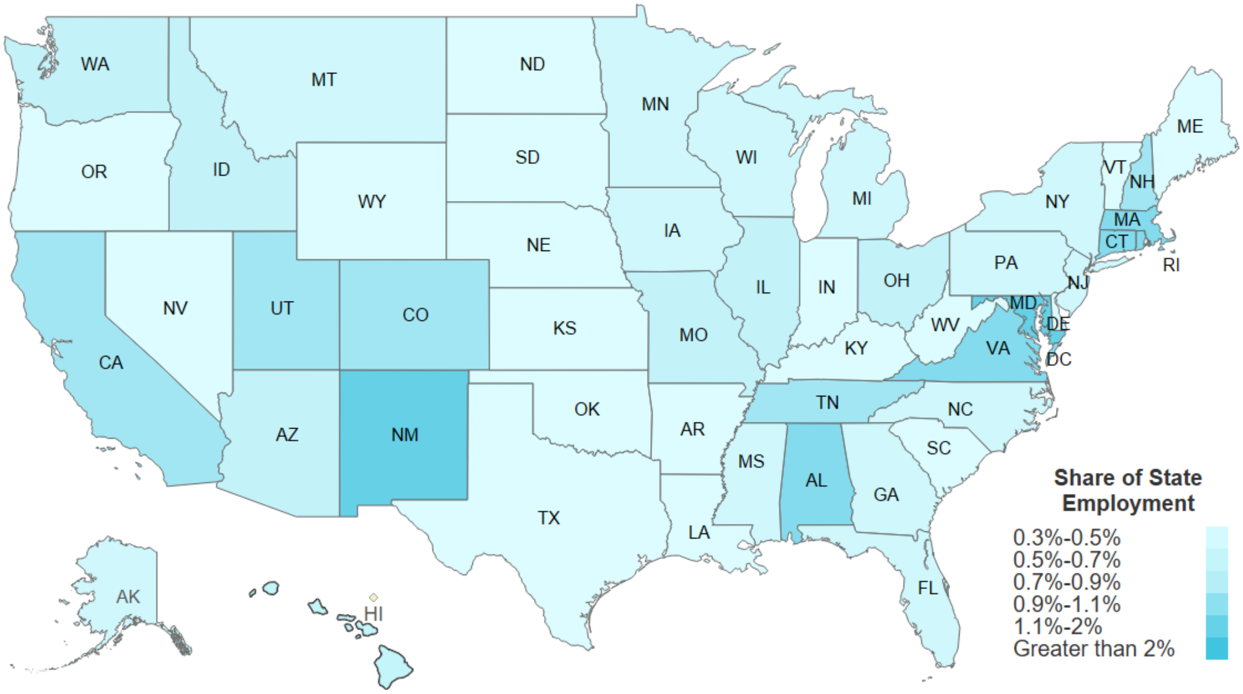
Table E-1. Economic Impacts of Federal R&D Investment on the US Economy, 2018

	Direct Impacts	Indirect Impacts	Induced Impacts	Total Impacts	Total / Direct (“Multiplier”)[d]
Employment (thousands of jobs)[a]	445.8	437.3	745.6	1,628.7	3.7
Labor Income ($billions)[b]	$50.9	$33.4	$41.2	$125.5	2.5
Value Added ($billions)	$70.6	$54.8	$71.2	$196.7	2.8
Tax Impact ($billions)[c]	$13.0	$10.5	$15.4	$38.9	3.0

Source: PwC calculations using the IMPLAN modeling system (2018 database).
Note: Details may not add to totals due to rounding.
[a] Employment is defined as the number of payroll and self-employed jobs, including part-time jobs.
[b] Labor income is defined as wages and salaries and benefits as well as proprietors’ income.
[c] Taxes include federal and state and local income and non-income taxes.
[d] Economic multiplier represents the overall (direct, indirect, and induced) impact relative to the direct impact.

The economic impact of federal R&D investment can be seen across the United States. Federal R&D investment directly and indirectly supported at least 1,000 jobs in every state in 2018, and more than 10,000 jobs in 31 states. Federal R&D investment supported more than 160,000 jobs in both California and Maryland. The share of state-wide employment supported by federal R&D investment (including direct, indirect and induced impacts) in each state ranges from 0.3 percent in Nevada to 5.3 percent in New Mexico (see **Figure E-1**, below).

Figure E-1. Share of Employment Directly and Indirectly Supported by Federal R&D Investment, 2018



Source: PwC calculations.

By sector, federal funding of defense R&D directly and indirectly supported 701,000 jobs in 2018, federal funding of energy R&D supported 112,100 jobs, and federal funding of health R&D supported 449,200 jobs.

Lastly, estimating economic impacts under a scenario in which federal funding for R&D investment grows from 0.6 percent of GDP in 2018 to 1.0 percent of GDP in 2030, we find federal R&D investment would directly and indirectly support 2.7 million annual jobs on average over the period 2021 to 2030, and cumulatively support $2.3 trillion of labor income, $3.7 trillion in value added, and $622.9 billion in tax payments.

> *“Under a scenario in which federal funding for R&D investment grows from 0.6 percent of GDP in 2018 to 1.0 percent of GDP in 2030, we find federal R&D investment would directly and indirectly support 2.7 million annual jobs on average over the period 2021 to 2030, and cumulatively support $2.3 trillion of labor income, $3.7 trillion in value added, and $622.9 billion in tax payments.”*

Impacts of Federal R&D Investment on the US Economy

I. Introduction

Investment in research and development (R&D) contributes to national economic growth in the short run through job creation and income gains and in the long run through the generation of knowledge, skills, and technological improvements that enhance the productivity of workers both inside and outside the organization doing the research.[7] In addition, R&D contributes to advancements that enhance human health, strengthen national security, and protect the environment. While the private sector funds and performs most R&D in the United States, the public sector (primarily the federal government) plays a vital role in funding R&D, especially early-stage basic and applied research, that would not otherwise occur due to the inability of private entities to fully capture the economic benefits of their investments.

Breakthrough Energy engaged PwC to assess the short- and long-term economic impacts of public R&D investment in the United States, with a focus on federal R&D investment in the defense, energy, and health sectors. This report provides a review of recent findings on the economic contributions of public R&D investments and provides new estimates of the national and state-level economic impacts of federal R&D funding by sector based on the latest available government data.

The analysis quantifies the short-run economic impacts of federal R&D investment as of 2018 and considers a scenario of a sustained increased in federal R&D investment to derive potential impacts over the next decade, 2021-2030. Economic impacts are measured in terms of employment, labor income, value added, and tax revenue.[8] The analysis accounts for the direct impacts from R&D performers, the indirect impacts resulting from the supply chain to R&D performers, and the induced impacts resulting from expenditures of labor income earned by employees of R&D performers and their supply chain. In addition, the study discusses potential long-term impacts of current and enhanced federal R&D investment in terms of productivity growth, innovation, and technological progress.

The rest of this report is organized as follows. **Section II** provides an overview of R&D in the United States, including the latest available data on federally funded R&D. **Section III** provides a review of recent findings on the economic contributions of public R&D investments, documenting empirical results as well as major innovations that have resulted from federally funded R&D. **Section IV** presents PwC's estimates of the economic impacts of federal R&D investment by sector at the national and state level in 2018. **Section V** presents PwC's estimates of the economic impacts of a scenario of increased federal R&D investment from 2021 through 2030. Detailed results by state and an overview of the methodology are provided in the appendices.

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[7] See, for example, the study by the Congressional Budget Office, "R&D and Productivity Growth," June 2005, available at https://www.cbo.gov/sites/default/files/109th-congress-2005-2006/reports/06-17-r-d.pdf.

[8] Value added refers to the additional value created at a particular stage of production; the sum of all value added in the US is gross domestic product ("GDP"). Value added consists of: employee compensation, proprietors' income, income to capital owners from property, and indirect business taxes (including excise taxes, property taxes, fees, licenses, and sales taxes paid by businesses).

II. Overview of R&D in the United States

At least since Nobel laureate Paul Romer's contributions to economic theory three decades ago, economists have understood that R&D is a key determinant of technological progress and ultimately economic growth.[9] Studies have found a strong connection between R&D spending, innovative output such as patents, and productivity (output per worker).[10] The OECD has found that a 10 percent increase in the stock of patents in the United States is associated with about a 3 percent increase in total capital and a 2 percent increase in employment.[11] The OECD has also found that a 1 percent increase in the stock of R&D leads on average to a rise in GDP of 0.05-0.15 percent.[12]

The knowledge that arises from R&D is close to what economists define as a "public good": First, one person's use of it does not diminish the ability of others to use it, but rather it can be reused in multiple applications (economists call this a "non-rival" good), and, second, it is difficult to exclude others from its use, e.g., by preventing its dissemination (economists call this a "non-excludable" good).[13] As such, for many R&D projects private companies can capture only a fraction of the total benefits to society, leading to underinvestment in R&D relative to what is socially optimal. This in turn leads to a need for public funding of R&D investment to fill the gap. As Romer states, "too little human capital is devoted to research."[14] Estimates vary but most studies find that total social returns are two to three times as large as the private returns on R&D investment.[15]

In the United States, business provides the majority of R&D funding, with governments, educational institutions, and other nonprofit organizations accounting for about 30 percent of national R&D investment. According to the latest available data from the National Science Foundation, total US operational expenditures for R&D amounted to $580 billion in 2018, of

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[9] Paul Romer, "Endogenous Technological Change," *Journal of Political Economy*, Vol. 98(5), pp. 71-102, 1990.

[10] Rachel Griffith, Elena Huergo, Jacques Mairesse, and Bettina Peters, "Innovation and Productivity Across Four European Countries," *Oxford Review of Economic Policy,* Vol. 22(4), pp. 483-498, 2006, available at: http://oxrep.oxfordjournals.org/content/22/4/483.

[11] OECD, "Supporting Investment in Knowledge Capital, Growth and Innovation," 2013, page 70, available at: http://www.oecd.org/sti/inno/newsourcesofgrowthknowledge-basedcapital.htm.

[12] OECD, "Science, Technology and Industry Outlook - Drivers of Growth: Information Technology, Innovation and Entrepreneurship," 2001, available at: http://www.oecd-ilibrary.org/industry-and-services/science-technology-and-industry-outlook-2001_sti_outlook-2001-en. Referenced in: OECD, "Tax Incentives for Research and Development: Trends and Issues," 2001, page 6, available at: http://www.oecd.org/science/inno/2498389.pdf.

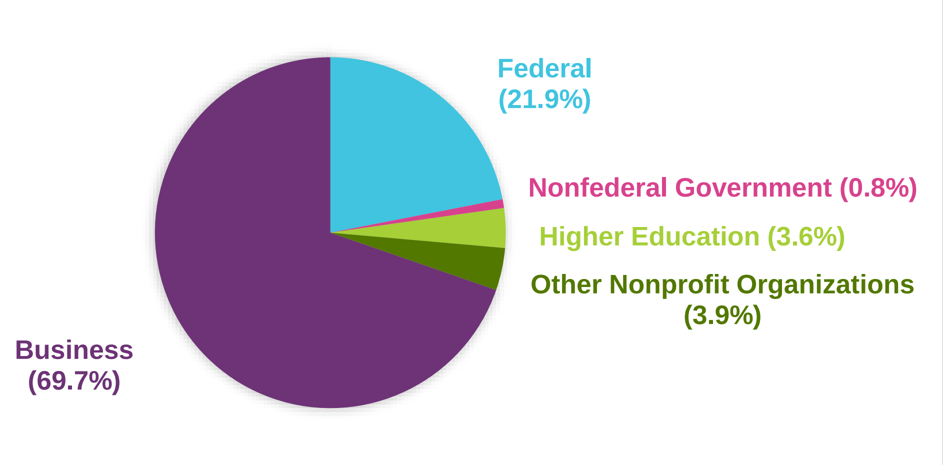
[13] Rather than a pure public good, which is a fully non-rival and non-excludable good, Romer describes knowledge or technology as a "non-rival, partially excludable good." See Paul Romer, "Endogenous Technological Change," *Journal of Political Economy*, Vol. 98(5), pp. 71-102, 1990.

[14] Paul Romer, "Endogenous Technological Change," *Journal of Political Economy*, Vol. 98(5), pp. 71-102, 1990.

[15] Sumiye Okubo, Carol A. Robbins, Carol E. Moylan, Brian K. Sliker, Laura I. Schultz, and Lisa S. Mataloni, "R&D Satellite Account: Preliminary Estimates," US Bureau of Economic Analysis/National Science Foundation, September 2006, available at: https://www.bea.gov/news/2006/research-and-development-satellite-account; Lew Sveikauskas, "R&D and Productivity Growth: A Review of the Literature," US Bureau of Labor Statistics, Working Paper 408, September 2007, available at: https://www.bls.gov/osmr/research-papers/2007/pdf/ec070070.pdf; Bronwyn H. Hall, Jacques Mairesse and Pierre Mohnen, "Measuring the Returns to R&D," NBER working paper 15622, December 2009, available at: http://www.nber.org/papers/w15622.pdf.

which $404 billion (69.7 percent) was funded by business, $127 billion (21.9 percent) by the federal government, $5 billion (0.8 percent) by state and local governments, $21 billion (3.6 percent) by colleges and universities, and $23 billion (3.9 percent) by other nonprofit organizations (see **Figure 1**, below).[16]

Figure 1. US R&D Operational Expenditures by Funder, 2018



Source: National Science Foundation.
Note: Data exclude expenditures for R&D plant and equipment.

As a share of GDP, federally funded R&D fell to 0.62 percent in 2018 – the lowest level since records began in 1953 (see **Figure 2**, below). Federally funded R&D as a share of GDP peaked at 1.86 percent in 1964 during the Cold War defense buildup and space race that successfully landed a man on the moon in 1969. Since the moon landing, federally funded R&D has largely tracked the decline in the federal discretionary budget, which went from 12 percent of GDP in 1969 to 6.2 percent in 2018.[17]

In contrast, business-funded R&D has trended higher throughout this period, from 0.58 percent of GDP in 1953 to 1.96 percent of GDP in 2018. Other R&D funding sources, consisting of state and local governments, universities, and nonprofits, have increased from essentially zero (0.03 percent of GDP) in 1953 to 0.24 percent of GDP in 2018.

R&D has three main components: **basic research**, which is “undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts”; **applied research**, which is “directed primarily towards a specific practical aim or objective”; and **development**, which is “directed at producing new products or processes or improving existing

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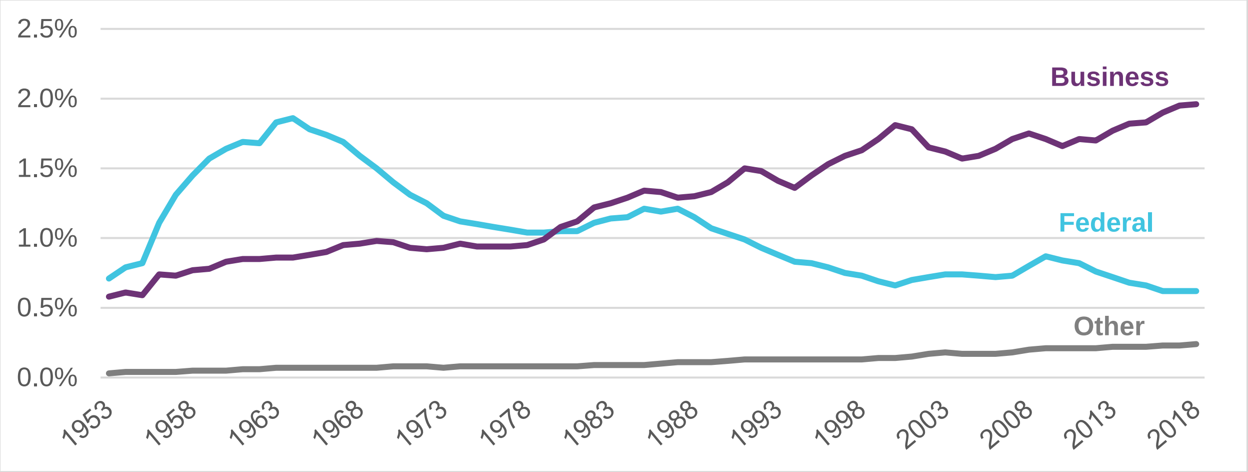
[16] National Science Foundation, *National Patterns of R&D Resources,* available at https://www.nsf.gov/statistics/natlpatterns/.

[17] Over the same period, federal mandatory spending went from 5.5 percent of GDP in 1969 to 12.4 percent in 2018. Matt Hourihan and David Parkes, “Federal R&D Budget Trends: A Short Summary,” American Association for the Advancement of Science, January 2019, available at https://www.aaas.org/sites/default/files/2019-01/AAAS%20R%26D%20Primer%202019.pdf; Congressional Budget Office, *Historical Budget Data*, available at https://www.cbo.gov/data/budget-economic-data

products or processes."[18] The rise of business-funded R&D largely reflects an increase in business-funded development, while the decline of federally funded R&D largely reflects a decline in federally funded development (see **Figures 3** and **4**, below). Federal R&D is now primarily focused on basic and applied research as opposed to development – a reversal from the 1950s and 1960s. Development represented about two-thirds of both federally funded and business-funded R&D in the 1950s and 1960s. By 2018, the development share of business-funded R&D had increased to 78 percent while the development share of federally funded R&D had decreased to 37 percent.[19] As described by the National Research Council, "increasingly, government is called upon to fund high-risk, long-term research and some types of applied research, particularly proof-of-concept research, at least to the point where the risks of investment in such research are reduced to attract private-sector funding."[20]

Figure 2. US R&D Operational Expenditures by Funder as a Share of GDP, 1953-2018



Source: National Science Foundation.
Note: "Other" consists of state and local governments, educational institutions, and other nonprofit organizations. Data exclude expenditures for R&D plant and equipment. From 2016 forward, the federal data exclude expenditures for preproduction development (about 5% of federal R&D in 2018), due to guidance by the Office of Management and Budget making the definition of R&D more consistent between governmental and non-governmental sectors.[21]

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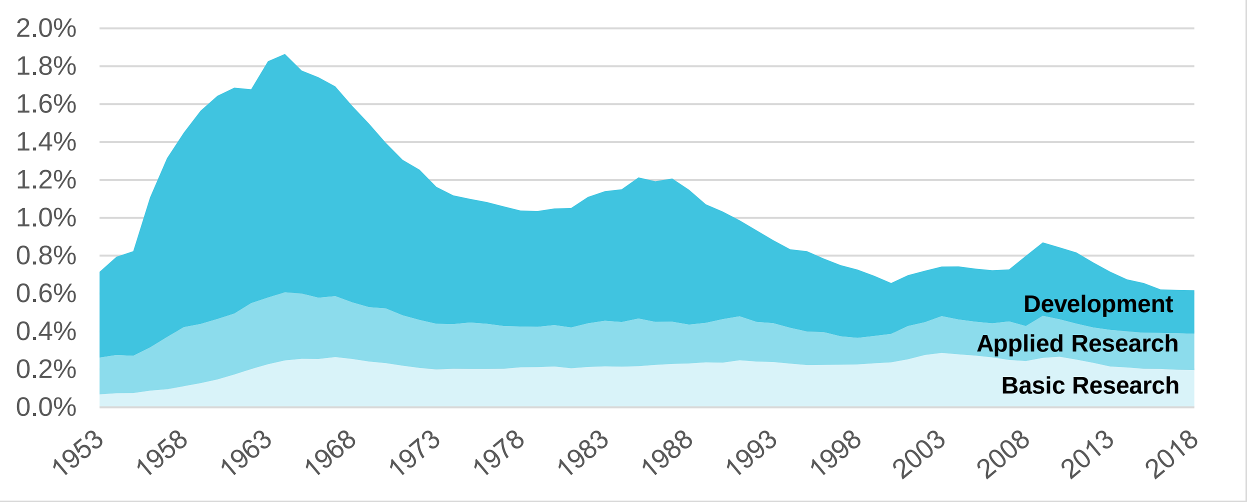
[18] Office of Management and Budget, "Circular No. A-11: Preparation, Submission, and Execution of the Budget", Section 84, December 2019, available at https://www.whitehouse.gov/wp-content/uploads/2018/06/a11.pdf.

[19] Over the period 1953 to 1969, the development share of federally funded R&D averaged 68 percent while the development share of business-funded R&D averaged 67 percent. National Science Foundation, *National Patterns of R&D Resources,* available at https://www.nsf.gov/statistics/natlpatterns/.

[20] National Research Council, *Furthering America's Research Enterprise*, 2014, quoted in Matt Hourihan and David Parkes, "Federal R&D Budget Trends: A Short Summary," American Association for the Advancement of Science, January 2019, available at https://www.aaas.org/sites/default/files/2019-01/AAAS%20R%26D%20Primer%202019.pdf.

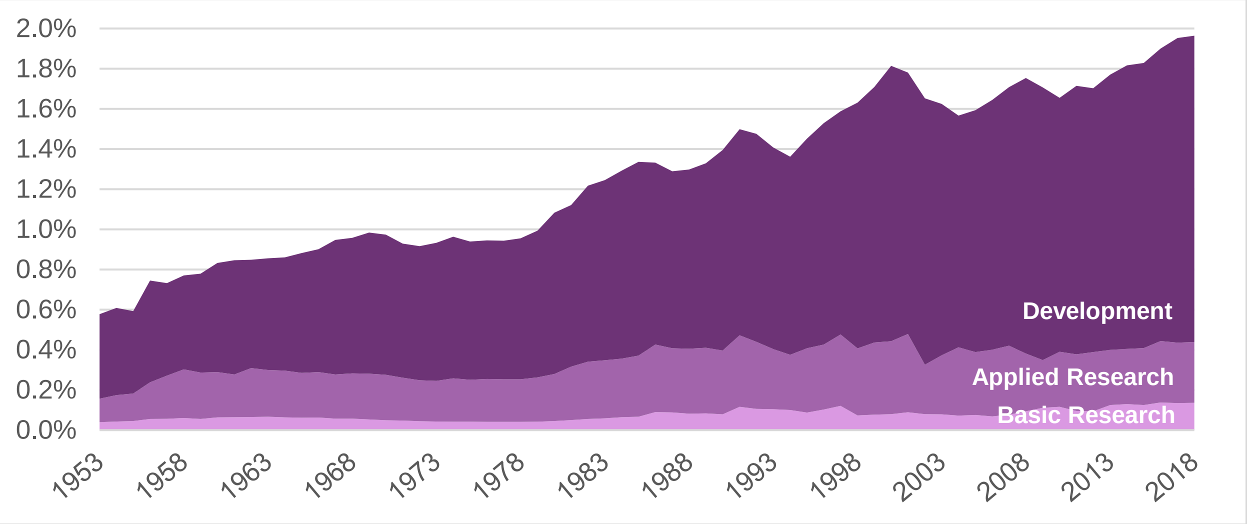
[21] Matt Hourihan and David Parkes, "Federal R&D Budget Trends: A Short Summary," American Association for the Advancement of Science, January 2019, available at https://www.aaas.org/sites/default/files/2019-01/AAAS%20R%26D%20Primer%202019.pdf.

Figure 3. Federally Funded R&D Operational Expenditures by Component as a Share of GDP, 1953-2018



Source: National Science Foundation.
Note: Data exclude expenditures for R&D plant and equipment. From 2016 forward, the federal data exclude expenditures for preproduction development (about 5% of federal R&D in 2018).

Figure 4. Business Funded R&D Operational Expenditures by Component as a Share of GDP, 1953-2018



Source: National Science Foundation.
Note: Data exclude expenditures for R&D plant and equipment.

By federal agency, most federal funding for R&D (79 percent of federal outlays in fiscal year 2018) is through the Department of Defense, Department of Energy, and Department of Health and Human Services.[22] By performer as of 2018, 29.0 percent of federal R&D is performed intramurally (i.e., by the federal government) and another 16.5 percent is performed by federally

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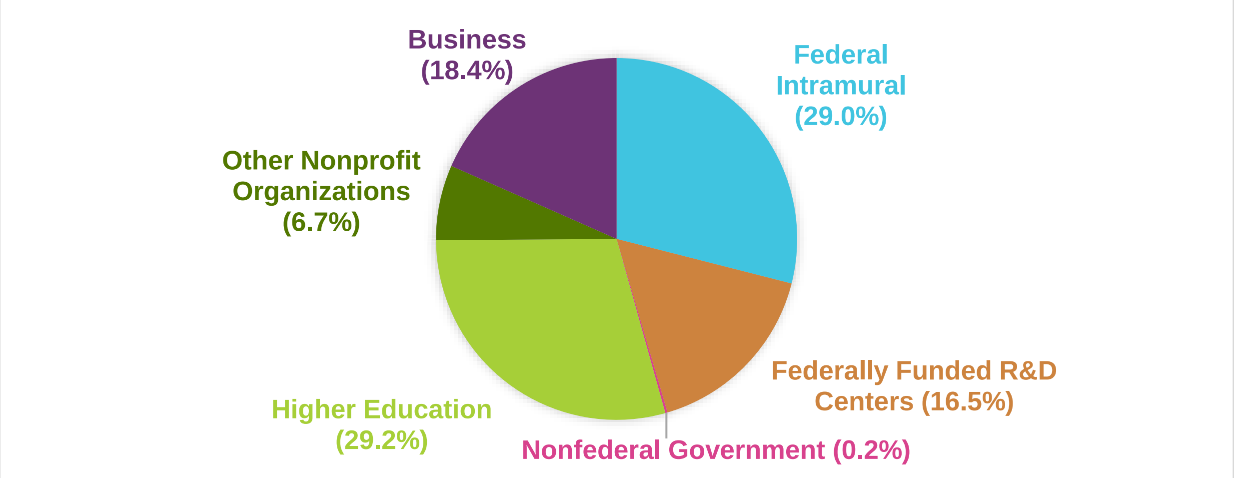
[22] National Science Foundation, *Survey of Federal Funds for Research and Development,* available at https://ncsesdata.nsf.gov/fedfunds/2018/.

funded R&D centers, e.g., the Department of Energy's 17 national labs (see **Figure 5**, below). The remainder of federally funded R&D is performed by colleges and universities (29.2 percent), business (18.4 percent), other nonprofits (6.7 percent), and state and local governments (0.2 percent).[23]

Figure 5. Federal R&D Operational Expenditures by Performer, 2018



Source: National Science Foundation.
Note: Data exclude expenditures for R&D plant and equipment.

A number of studies have identified certain supporting conditions for maximizing the economic impacts of public R&D. These studies find that a key input to increasing research productivity is increasing human capital through education and immigration policy.[24] Other research indicates that openness to trade is supportive of innovation, due to expanded markets for innovative outputs and inputs as well as faster diffusion of knowledge.[25]

Other supporting conditions have to do with the design of R&D programs. Studies have found that giving academic researchers ownership of their innovations leads to more innovation as well as commercial development, e.g., through patenting and launching of business startups.[26] Looking at the Defense Department's Advanced Research Projects Agency (DARPA), a recent study found that features that led to the agency's success are its "organizational flexibility on an

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[23] National Science Foundation, *National Patterns of R&D Resources,* available at https://www.nsf.gov/statistics/natlpatterns/.

[24] Nicholas Bloom, John Van Reenen and Heidi Williams, "A Toolkit of Policies to Promote Innovation," *Journal of Economic Perspectives*, Vol. 33(3), pp. 163-184, 2019. See also Zhangkai Huang, Gordon M. Phillips, Jialun Yang, Yi Zhang, "Education and Innovation: The Long Shadow of the Cultural Revolution," NBER Working Paper No. 27107, May 2020, and Petra Moser, Alessandra Voena, and Fabian Waldinger, "German Jewish Émigrés and US Invention." *American Economic Review*, Vol. 104(10), pp. 3222–55, 2014.

[25] Nicholas Bloom, John Van Reenen and Heidi Williams, "A Toolkit of Policies to Promote Innovation," *Journal of Economic Perspectives*, Vol. 33(3), pp. 163-184, 2019. See also Philippe Aghion, Antonin Bergeaud, Matthieu Lequien, and Marc J. Melitz, "The Impact of Exports on Innovation: Theory and Evidence," NBER Working Paper 24600, 2018.

[26] Saul Lach and Mark Schankerman, "Incentives and Invention in Universities," *RAND Journal of Economics*, Vol. 39(2), pp. 403–33, 2008; Hans K. Hvide and Benjamin F. Jones, "University Innovation and the Professor's Privilege," *American Economic Review*, Vol. 108(7), pp. 1860–98, 2018.

administrative level and significant authority given to program directors to design programs, select projects, and actively manage projects."[27]

It should be noted that in addition to direct funding of R&D, many governments (US federal, state, and foreign) have introduced research tax credits to incentivize private sector R&D investment.[28] The federal research and experimentation (R&E) tax credit, enacted in 1981, allows taxpayers to claim the credit with respect to incremental increases in research expenses. Based on the most recent available data, US corporate and individual taxpayers claimed R&E tax credits totaling approximately $16.1 billion in 2016 – about 14 percent of federal R&D spending that year.[29] Many studies have found the federal R&E credit is effective in that it substantially increases private sector R&D activities.[30] For example, in a review of studies, the Joint Committee on Taxation found that an additional dollar of the federal R&E credit produces an additional dollar of private sector investment in R&D.[31] Similarly, research tax credits provided by many states have been found to be effective as well.[32] Like direct federal funding for R&D investment, research tax credits provide an alternative method of addressing the underinvestment in R&D by private businesses due to their inability to capture the total return from R&D investments.

Compared with other OECD countries, relative to GDP, the United States ranks below average in terms of tax support for R&D, based on data compiled by the OECD for 2016 and 2017.[33] Countries with more generous tax support for R&D relative to GDP include Belgium, France, the UK, the Netherlands, Austria, Italy, Ireland, Australia, Korea, Canada, Norway, Japan, Portugal, Slovenia, and Iceland.[34] However, relative to GDP, the United States ranks relatively high in

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[27] Pierre Azoulay, Erica Fuchs, Anna Goldstein and Michael Kearney, "Funding Breakthrough Research: Promises and Challenges of the ARPA Model," in Josh Lerner and Scott Stern, eds., *Innovation Policy and the Economy*, Volume 19, 2019.

[28] Many foreign governments provide R&D tax credits and other tax incentives for private sector R&D investment.

[29] Internal Revenue Service Statistics of Income. This represents the tentative R&E tax credit and does not account for limitations due to current-year tax liability, carryforward and carryback rules, etc. The US Treasury Department estimates that only about half of the tentative R&E tax credit amount is able to be used to reduce current year taxes. See US Treasury Office of Tax Analysis, "Research and Experimentation (R&E) Credit," page 3, October 12, 2016, available at https://www.treasury.gov/resource-center/tax-policy/tax-analysis/Documents/RE-Credit.pdf.

[30] See, for example, US Treasury Office of Tax Analysis, "Research and Experimentation (R&E) Credit," October 12, 2016, available at https://www.treasury.gov/resource-center/tax-policy/tax-analysis/Documents/RE-Credit.pdf.

[31] Joint Committee on Taxation, "Economic Growth and Tax Policy," JCX-47-15, February 20, 2015.

[32] Catherine Fazio, Jorge Guzman, and Scott Stern, "The Impact of State-Level Research and Development Tax Credits on the Quantity and Quality of Entrepreneurship, *Economic Development Quarterly*," April 29, 2020, available at https://journals.sagepub.com/doi/full/10.1177/0891242420920926.

[33] OECD, "Measuring Tax Support for R&D and Innovation," June 2020, available at http://www.oecd.org/sti/rd-tax-stats.htm. The data exclude income-based tax incentives, such as patent boxes that have been implemented in many European countries. See Tax Foundation, "Patent Box Regimes in Europe," June 20, 2019, available at https://taxfoundation.org/patent-box-regimes-europe-2019/.

[34] In addition to its low rank in terms of tax subsidies for R&D relative to GDP, the United States also ranks below the average of other OECD countries in terms of tax incentives for R&D per dollar of marginal private R&D investment. Among 48 OECD and other countries, in 2019 the United States ranked behind 34 other countries for tax incentives for large profitable companies; for small loss-making companies, the United States ranked behind 28 other countries. See, OECD, "Tax subsidy rates on R&D expenditures, 2019," available at http://www.oecd.org/sti/rd-tax-incentive-indicators.htm.

terms of direct government funding of R&D performed by business, behind Russia (a non-OECD country), Korea, and Hungary. In terms of the combined measure of direct funding and tax support for business R&D, relative to GDP, the United States ranks above the OECD average but behind nine other countries: Russia, France, Belgium, the UK, Korea, Canada, Austria, Iceland, and Norway.

III. Recent Findings on the Economic Contributions of Public R&D Investments

This section provides a review of findings on the short- and long-run economic impacts of public R&D investment. The review focuses primarily on recently published empirical studies, which apply state-of-the-art econometric and statistical methods to historical episodes of public R&D investment and which mainly estimate long-run economic impacts. In addition to empirical studies, the review catalogues major innovations that have resulted from federally funded R&D over the long run, focusing on federally funded R&D in the defense, energy, and health sectors.

A. Long-Term Impacts on Innovation and Productivity

A June 2020 study analyzed the economic impacts of the historic increase in federal R&D spending that occurred during World War II, which created the foundation for today's federal R&D system.[35] In June 1940, President Roosevelt established the National Defense Research Committee (NDRC) to supplement existing military research and coordinate with private industry. The following year the organization was renamed the Office of Scientific Research and Development (OSRD) with its scope expanded to include development work and medical R&D.

> *"Federally funded R&D during World War II generated 7,910 inventions, 2,763 patents, and 2,470 scientific publications, resulting in multiple technological advances including radar, mass-produced penicillin, the atomic bomb, rocket technology, jet propulsion, radio communications, electronic computing, pesticides, and treatments for malaria."*

During the war, OSRD entered into 2,254 contracts with 461 distinct contractors primarily in industry and academia, which were worth a combined $7.4 billion in today's dollars – representing a more than 10-fold increase in federal R&D investment. Out of this effort came 7,910 inventions, 2,763 patents, and 2,470 scientific publications, resulting in multiple technological advances including radar, mass-produced penicillin, the atomic bomb, rocket technology, jet propulsion, radio communications, electronic computing, pesticides, and treatments for malaria. With the objective of attaining specific military demands and considering scientific feasibility, contracts were generally awarded based on the merit system. As a result, the research was concentrated in a few places with existing scientific expertise, e.g., MIT, Harvard, and CalTech, which formed the beginnings of a national lab network. These research centers attracted and incubated the nation's top scientists, many of whom dispersed after the war. Many of the contracts allowed researchers to retain patent rights, which enabled them to start businesses and turn federally funded research into commercial products.

The study compared US patenting at the county level and foreign patenting before and after the war (1930-1970), noting patent technology class and the share of US patents within each class that were OSRD-supported (OSRD rate). The study found that US counties with a relatively high OSRD rate experienced a spike in patenting during the war, followed by a contraction and then a sustained exponential growth in patenting at least through 1970. For a given county and

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[35] Daniel Gross and Bhaven Sampat, "Inventing the Endless Frontier: The Effects of the World War II Research Effort on Post-War Innovation," NBER Working paper 27375, June 2020.

patent technology class, the study found that a doubling of the OSRD rate over the course of the war resulted in 30 percent more patents in that technology area by 1970. The authors of the study attributed the effect both to agglomeration, i.e., the movement of scientists towards research clusters, and to an increase in per capita inventive productivity.

> *"A doubling of OSRD electronic-related patents in the 1940s in a given county is associated with roughly 60-65 percent higher employment in that county in the Communications and Electronics industries even some thirty to forty years later."*

Further, the study found evidence of a long-term boost to employment in the manufacturing industries most closely connected to OSRD patents. Specifically, the study found that a doubling of OSRD electronic-related patents in the 1940s in a given county is associated with roughly 60-65 percent higher employment in that county in the Communications and Electronics industries even some thirty to forty years later. According to the authors, "Our interpretation is that the OSRD not only deepened local technology clusters and increased local invention over the long-run, but also created jobs in associated manufacturing industries."[36]

> *"An increasing share of US patents rely on federally funded research, rising from less than 2 percent prior to World War II to more than 28 percent as of 2017."*

Looking at US patenting over much of the last century, a recent study published in *Science* traced bibliometric linkages in scientific publications and found that an increasing share of US patents rely on federally funded research, rising from less than 2 percent prior to World War II to more than 28 percent as of 2017.[37] By agency, Department of Defense funding generates the most patents, followed by funding for the Department of Health and Human Services and the Department of Energy. Startups are particularly reliant on federal research, with 35 percent of patents assigned to venture-backed companies citing federally supported research.

Another recent study focused on defense R&D spending to test whether publicly funded R&D "crowds out" or "crowds in" private R&D spending.[38] Crowding out occurs when publicly funded R&D displaces privately funded R&D that would otherwise occur. This might occur if there is a relatively fixed supply of researchers and other inputs to the R&D process.[39] Alternatively, crowding in could occur as a result of spillovers of publicly funded technological know-how that spur further research by other private sector firms.[40] Crowding in can also occur if some private sector firms have socially valuable research ideas to pursue but are unable to fund it privately

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[36] The authors noted they are not prepared to calculate a rate of return of OSRD investment, since they have not accounted for all relevant inputs.

[37] L. Fleming, H. Greene, G. Li, M. Marx, and D. Yao, "Government-Funded Research Increasingly Fuels Innovation," *Science*, June 21, 2019.

[38] Enrico Moretti, Claudia Steinwender, and John Van Reenen, "The Intellectual Spoils of War? Defense R&D, Productivity and International Spillovers," NBER Working paper No. 26483, November 2019.

[39] See, for example, Austan Goolsbee, "Does Government R&D Policy Mainly Benefit Scientists and Engineers?" *American Economic Review*, Vol. 88(2), pp. 298-302, 1998.

[40] On spillovers, see for example, Enrico Moretti, "The Effect of High-Tech Clusters on the Productivity of Top Inventors," NBER Working Paper No. 26270, September 2019, and "Workers' Education, Spillovers, and Productivity: Evidence from Plant-Level Production Functions." *American Economic Review,* Vol. 94 (3), pp. 656-690, 2004.

either due to an insufficient private return or due to capital market imperfections that prevent the firms from receiving sufficient external funding.

The study, which is based on R&D data by industry in the United States and 25 other developed countries from 1987 to 2009 as well as firm-level data in France from 1980 to 2015, found strong evidence of crowding in, estimating that, for a given industry and year, a 10 percent increase in public defense R&D investment causes an additional 4 percent increase in private R&D investment the following year. The analysis implies that current federal R&D investment in the defense sector of $58 billion in 2018 results in approximately $52 billion in additional private sector R&D investment.[41]

Further, the study found large and positive impacts on employment, rather than wages and input prices, which, the authors noted, is "consistent with a fairly elastic local supply of specialized R&D workers within an industry across countries, or across industries." The effect on employment of private sector R&D workers is approximately proportional to the effect on private sector R&D expenditures. Additionally, the study found evidence of spillovers across countries, such that increases in government-funded R&D in one country causes increases in private R&D in that country and in other countries.

Lastly, the study found that an increase in defense R&D results in a faster rate of growth in private sector productivity, i.e., output per worker (also known as total factor productivity). Specifically, for a given industry, a one percentage point increase in defense R&D intensity (the ratio of defense R&D to value added) is estimated to cause a 5 percent increase in the annual growth rate of total factor productivity in the short term. Regarding long-term impacts on productivity, the authors noted, "it is in principle possible that the effects are larger when looking at a longer time horizon, e.g., over decades, therefore our estimates are likely to be a lower bound of the true effect of public R&D subsidies on private R&D and productivity growth." On the other hand, the results likely overestimate the impact of public R&D since they do not account for the (opportunity) cost of financing public R&D, e.g., by raising taxes. However, as noted by the authors, "reallocating military expenditures away from inefficient uses toward funding for R&D would have limited opportunity costs." The authors concluded that "overall, our estimates suggest that cross-country differences in defense R&D play a role in explaining cross-country differences in private R&D investment, speed of innovation, and ultimately in productivity of private sector firms."

> *"Firms that received public funding for R&D increased their own spending on R&D by 70 cents for each dollar of government funding."*

The study is consistent with prior research, which has generally found that public R&D tends to be a complement rather than a substitute for private R&D.[42] For instance, one study found that firms that received public funding for R&D increased their own spending on R&D by 70 cents for each

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[41] Enrico Moretti, Claudia Steinwender, and John Van Reenen, "The Intellectual Spoils of War? Defense R&D, Productivity and International Spillovers," NBER Working paper No. 26483, November 2019. The study estimated that $71 billion of additional private sector R&D investment results from $78 billion of federal R&D investment that is categorized under the defense budget function in 2016.

[42] See, for instance, Paul A. David, Bronwyn H. Hall, and Andrew A. Toole, "Is Public R&D a Complement or Substitute for Private R&D? A Review of the Econometric Evidence," *Research Policy*, Vol. 29(4-5), pp. 497–529, April 2000.

dollar of government funding, and this effect was most evident for non-defense R&D.[43]

US defense-related R&D has contributed to a series of major technological breakthroughs and advances beyond the World War II era technologies mentioned above. The Global Positioning System (GPS), which uses ground stations, satellites, and receivers to triangulate location, was originally conceived and funded as a military project by the Department of Defense (DOD) in 1959 and began operating on a limited basis in 1978. During the 1980s researchers at the DOD's Defense Advanced Research Projects Agency (DARPA) reduced the size of the receivers to a handheld device, and in 1995 GPS became fully operational.[44] DARPA also funded the development of ARPANET, a precursor to the internet. From its origin as a network of five computers in 1969, ARPANET expanded with the support of DARPA to include new software-based protocols and standards (TCP/IP) as well as an early form of email. The National Science Foundation took over management of ARPANET in the 1980s, where it soon spread to academic institutions and evolved to become the internet.[45] DARPA currently funds hundreds of programs that are "high risk in pursuit of high payoff," such as research related to artificial intelligence, accelerated molecular discovery, high-altitude lighter-than-air vehicles, and advanced full range engines that can operate from low-speed takeoff through hypersonic flight.[46]

Turning to the impacts of health-related R&D, a recent study looked at the impact of NIH research funding on private sector patenting from 1980 to 2012, tracing linkages from NIH grants to scientific publications and patents.[47] The study found that, within a particular disease area, an additional $10 million of NIH funding results in 2.7 additional private sector patents, with no evidence of crowding out of private investment. As a measure of the private rate of return of NIH funding (i.e., not accounting for the social return), the authors used relationships between patents and drug sales to estimate that $10 million of NIH funding generates approximately $23.4 million in drug sales. The analysis implies that current NIH funding of $32 billion in federal outlays in fiscal year 2018 may lead to approximately 8,600 patents, roughly 22 FDA-approved drugs, and $75 billion in subsequent drug sales.[48]

> *"$10 million of NIH funding generates approximately $23.4 million in drug sales."*

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[43] Dominique Guellec and Bruno van Pottelsberghe de la Potterie, "The Impact of Public R&D Expenditure on Business R&D," *Economics of Innovation and New Technology,* Vol. 12(3), pp. 225–243, June 2003. The study found defense R&D performed intramurally and by universities has a crowding out effect on privately funded R&D, which the authors noted "might be due to the fact that defence-related funding crystallizes essentially into procurements (as opposed to grants), under which any technological invention belongs to the government."

[44] Peter L. Singer, "Federally Supported Innovations: 22 Examples of Major Technology Advances That Stem From Federal Research Support," The Information Technology & Innovation Foundation, February 2014, available at https://itif.org/publications/2014/02/03/federally-supported-innovations.

[45] Ibid.

[46] DARPA, "Our Research," available at https://www.darpa.mil/our-research.

[47] Pierre Azoulay, Joshua Graff Zivin, Danielle Li, and Bhaven Sampat, "Public R&D Investments and Private-sector Patenting: Evidence from NIH Funding Rules," *Review of Economic Studies*, Vol. 86, pp. 117-152, 2019. The study used discontinuities in NIH funding rules (which provide an exogenous, i.e., random, variation around the discontinuities) to identify the impact of NIH grants.

[48] National Science Foundation, *Survey of Federal Funds for Research and Development: Fiscal Years 2018-19,* Table 3, January 2020, available at https://ncsesdata.nsf.gov/fedfunds/2018/.

In addition, the authors found a substantial "cross-disease spillover" effect from NIH funding: more than half of patents resulting from NIH funding are for disease areas other than those on the original funding application. Lastly, the authors noted that the results may underestimate the impact of NIH funding because they only account for patents that explicitly cite NIH-funded research, missing, for example, benefits that flow from informal interactions at NIH-funded conferences, private sector hiring of NIH-funded trainees, and "applied epidemiological and clinical research that changes medical practice or health behaviors."

The Congressional Budget Office (CBO) has noted that "the knowledge or advancement of science that is produced specifically by federal spending is difficult to account for; the timeframes involved are often long; the efforts needed to achieve innovation may be increasing over time; and past performance may not offer a good prediction of future returns."[49] This seems particularly true in regards to health sector R&D, perhaps because the economic value of improvements in health and longevity goes uncounted in measures of national income. By one estimate, the improvement in longevity that occurred in the United States between 1950 and 1995 has been as economically valuable as all other sources of economic growth combined over this period.[50] The connection between health research and improvements in health is not well established, however some studies have been able to associate research with later outcomes.[51] One study examined the impact of new pharmaceutical introductions and found that the typical new drug approved by the FDA between 1970 and 1991 saves over 11,000 life-years annually.[52] A large part of the improvement in longevity since 1950 is due to progress against cardiovascular disease, which has been attributed to improvements in biomedical knowledge.[53] Another study estimated that the return to producing basic information about disease risk is about 30 to 1.[54]

> *"A large part of the improvement in longevity since 1950 is due to progress against cardiovascular disease, which has been attributed to improvements in biomedical knowledge."*

Regarding health sector innovations that have resulted from federal R&D investment, a study found that World War II era funding contributed to the development of vaccines for 10 diseases including influenza, pneumococcal pneumonia, and plague.[55] The study attributed this burst of innovation to the urgent needs of the US military, which understood the importance of disease control in times of war, and the active involvement of the US military as a partner in vaccine

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[49] Congressional Budget Office, "Estimating the Long-Term Effects of Federal R&D Spending: CBO's Current Approach and Research Needs," June 21, 2018, available at https://www.cbo.gov/publication/54089.

[50] William Nordhaus, "The Health of Nations: The Contribution of Improved Health to Living Standards," in Murphy and Topel, eds., *Measuring the Gains from Medical Research*, pp. 9–40, 2003.

[51] Kevin M. Murphy and Robert H. Topel, eds., *Measuring the Gains from Medical Research*, 2003.

[52] Frank Lichtenberg, "Pharmaceutical Innovation, Mortality Reduction, and Economic Growth," in Murphy and Topel, eds., *Measuring the Gains from Medical Research*, 2003.

[53] Maria G. M. Hunink, Lee Goldman, Anna N. A. Tosteson, et al, "The Recent Decline in Mortality From Coronary Heart Disease, 1980-1990: The Effect of Secular Trends in Risk Factors and Treatment," *JAMA*, Vol. 277(7), pp. 535–542, 1997; E. Braunwald, "Shattuck Lecture--Cardiovascular Medicine at the turn of the Millennium: Triumphs, Concerns, and Opportunities," *New England Journal of Medicine*, Vol. 337(19), pp. 1360-1369, 1997.

[54] David Cutler and Srikanth Kadiyala, "The Return to Biomedical Research: Treatment and Behavioral Effects," in Murphy and Topel, eds., *Measuring the Gains from Medical Research*, 2003.

[55] Kendall Hoyt, "Vaccine Innovation: Lessons from World War II," *Journal of Public Health Policy,* Vol. 27(1), pp. 38-57, 2006.

development, i.e., the military's advanced record-keeping and controlled populations proved ideal for quickly determining the safety and efficacy of vaccines.

Shortly after World War II, federal funding of research into heart disease led to the Framingham Heart Study, one of the first long-term cohort studies of its kind. Now considered "the crown jewel of epidemiology," Framingham led to the identification of the major causal risk factors for cardiovascular disease and stroke and more generally led the medical profession to emphasize disease prevention and modifiable risk factors.[56]

> *"NIH research contributed to the development of a vaccine for Haemophilus influenza type b (Hib), once the leading cause of bacterial meningitis in children."*

In the 1980s, NIH research contributed to the development of a vaccine for Haemophilus influenza type b (Hib), once the leading cause of bacterial meningitis in children.[57] During this time, NIH also funded research that contributed to the development of antiretroviral drugs for the treatment of HIV.[58] Between 1990 and 2003, NIH and DOE jointly provided $3.8 billion in funding for the Human Genome Project, which is estimated to have resulted in an economic impact of $965 billion between 1988 and 2012, due to associated research and genomics industry activity.[59]

NIH funding also contributed to a series of advances related to magnetic resonance imaging (MRI) technology, including many in recent years.[60] For instance, NIH funding led to the development of an MRI contrast agent that is metal-free and safe to use.[61] NIH researchers developed low-field MRI technology that improves image quality of the lungs and other internal structures of the body.[62]

More recently, some NIH research and funding has focused on COVID-19. On February 19, 2020, researchers published the results of a study funded by NIH's National Institute of Allergy and Infectious Diseases (NIAID) that identifies the structural characteristics of the novel coronavirus that causes COVID-19, revealing potential targets for development of vaccines and

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[56] National Institutes of Health, "The Framingham Heart Study: Laying the Foundation for Preventive Health Care," available at https://www.nih.gov/sites/default/files/about-nih/impact/framingham-heart-study.pdf.

[57] National Institutes of Health, "Childhood Hib Vaccines: Nearly Eliminating the Threat of Bacterial Meningitis," available at https://www.nih.gov/sites/default/files/about-nih/impact/childhood-hib-vaccines-case-study.pdf.

[58] Peter L. Singer, "Federally Supported Innovations: 22 Examples of Major Technology Advances That Stem From Federal Research Support," The Information Technology & Innovation Foundation, February 2014, available at https://itif.org/publications/2014/02/03/federally-supported-innovations.

[59] Ibid.

[60] National Institutes of Health, "Magnetic Resonance Imaging (MRI)," available at https://www.nibib.nih.gov/science-education/science-topics/magnetic-resonance-imaging-mri.

[61] National Institutes of Health, "NIH-Funded Researchers Develop Metal-Free MRI Contrast Agent," October 6, 2017, available at https://www.nibib.nih.gov/news-events/newsroom/nih-funded-researchers-develop-metal-free-mri-contrast-agent

[62] National Institutes of Health, "NIH Researchers Develop MRI with Lower Magnetic Field for Cardiac and Lung Imaging," October 1, 2019, available at https://www.nih.gov/news-events/news-releases/nih-researchers-develop-mri-lower-magnetic-field-cardiac-lung-imaging.

treatment.[63] On May 22, 2020, NIAID published the results of its study finding that remdesivir, an antiviral treatment used to treat Ebola, shortened the time to recovery from COVID-19 from 15 to 11 days.[64] Other recent NIH research has found that the off-label use of acalabrutinib, which has been used to treat certain cancers, reduces respiratory distress resulting from COVID-19.[65]

> *"The net realized economic benefits associated with federal energy efficiency programs over the 22-year period were approximately four times the size of the investment."*

Turning to the impacts of energy-related R&D, in a study of the US Department of Energy's (DOE) R&D investment related to energy efficiency and fossil energy from 1978 to 2000, the National Research Council found the programs "have yielded significant benefits (economic, environmental, and national security-related)" and made "important additions to the stock of engineering and scientific knowledge in a number of fields."[66] The study analyzed a representative sample of programs and evaluated them on a "net realized" basis, i.e., accounting for the resulting benefits of technology developed during the 22-year period (but not for technology developed after the year 2000).[67] The study found that the net realized economic benefits associated with federal energy efficiency programs over the 22-year period were approximately four times the size of the investment, and included improvements in the energy efficiency of refrigerators, insulation, windows, and buildings. In addition, the study identified realized benefits in terms of the environment (e.g., indoor air quality, infiltration, and ventilation) and national security (e.g., advanced turbine systems). The study also identified numerous technologies funded by energy efficiency programs that were "unrealized", i.e., still in the research stage as of the year 2000, including compact fluorescent lighting and advanced batteries for electric vehicles.

Regarding fossil energy programs, the study found that the net realized economic benefits associated with these programs over the 22-year period were approximately equal to the investment, and included seismic technology for reservoir characterization and field demonstrations of extraction technologies. In addition, the study identified realized benefits in terms of the environment (e.g., control of oxides of nitrogen) and national security (e.g., improved enhanced oil recovery). The study identified numerous technologies funded by fossil energy programs that were unrealized as of the year 2000, including hydraulic fracturing technology, which later revolutionized the US oil and gas industry.

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[63] National Institutes of Health, "Novel Coronavirus Structure Reveals Targets for Vaccines and Treatments," March 3, 2020, available at https://www.nih.gov/news-events/nih-research-matters/novel-coronavirus-structure-reveals-targets-vaccines-treatments.

[64] National Institutes of Health, "Early Results Show Benefit of Remdesivir for COVID-19," June 2, 2020, available at https://www.nih.gov/news-events/nih-research-matters/early-results-show-benefit-remdesivir-covid-19.

[65] National Institutes of Health, "Cancer Drug May Reduce Symptoms of Sever COVID-19," June 16, 2020, available at https://www.nih.gov/news-events/nih-research-matters/cancer-drug-may-reduce-symptoms-severe-covid-19.

[66] National Research Council, *Energy Research at DOE: Was it Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000*, 2001.

[67] The study did not use a present discounted value approach to evaluating costs and benefits, but instead adjusted costs and benefits for inflation and compared the sum of costs over the 22-year period to the sum of benefits.

Modern hydraulic fracturing and horizontal drilling in the United States has opened up vast and previously untapped reserves of natural gas and oil in shale and other hard rock formations, enabling the United States to become the world's largest producer of oil and natural gas.[68] DOE's National Energy Technology Lab was instrumental in developing these and other associated technologies, including foam fracturing technology, oriented coring and fractographic analysis, large-volume hydraulic fracturing, and electromagnetic telemetry.[69]

DOE also funded research that led to the development of lithium-ion batteries, which have multiple uses from computers to solar power storage and enabled the development of mobile phones and electric plug-in vehicles. DOE funded the research of M. Stanley Whittingham and John Goodenough, who won the Nobel Prize for their work developing lithium-ion batteries.[70] In the 1980s and 1990s, DOE funded about $376 million of R&D related to advanced batteries for electric cars, particularly through its participation beginning in 1991 in the United States Advanced Battery Consortium (USABC), a joint government-industry program.[71] Researchers at Argonne National Lab and the Office of Energy Efficiency and Renewable Energy contributed to development of a cathode technology that is now widely used in plug-in electric vehicle batteries. DOE continues to support battery research through its national labs, Office of Science collaborations with a number of universities, and six Energy Frontier Research Centers that focus on batteries (Center for Synthetic Control Across Length-scales for Advancing Rechargeables, Center for Electrochemical Energy Science, Center for Mesoscale Transport Properties, Breakthrough Electrolytes for Energy Storage, Fluid Interface Reactions, Structures and Transport Center, and Nanostructures for Electrical Energy Storage).[72]

"Researchers at Argonne National Lab and the Office of Energy Efficiency and Renewable Energy contributed to development of a cathode technology that is now widely used in plug-in electric vehicle batteries."

> *"DOE funding contributed to advancements in LED lighting, the widespread use of which saved US consumers an estimated $12 billion in 2017."*

DOE funding has contributed to a number of advancements in lighting, particularly relating to light-emitting diode (LED) based solid-state lighting, which is now the most energy-efficient lighting technology. Since 2000, DOE has invested about $480 million in 322 solid-state lighting R&D projects,

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[68] US Energy Information Administration, "The U.S. Leads Global Petroleum and Natural Gas Production with Record Growth in 2018," August 20, 2019, available at https://www.eia.gov/todayinenergy/detail.php?id=40973; API, "Introduction – What is Hydraulic Fracturing?," available at https://www.api.org/oil-and-natural-gas/energy-primers/hydraulic-fracturing.

[69] Department of Energy: National Energy Technology Laboratory, "Shale Gas: Applying Technology to Solve America's Challenges."

[70] Department of Energy: Office of Science, "Charging Up the Development of Lithium-Ion Batteries," October 15, 2019, available at https://www.energy.gov/science/articles/charging-development-lithium-ion-batteries.

[71] National Research Council, *Energy Research at DOE: Was it Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000*, 2001.

[72] Department of Energy: Office of Science, "Charging Up the Development of Lithium-Ion Batteries," October 15, 2019, available at https://www.energy.gov/science/articles/charging-development-lithium-ion-batteries.

resulting in 316 patents applied for or awarded and millions of commercial products. DOE estimates the energy savings from these commercial products currently exceeds $10 billion.[73] DOE continues to fund R&D in this area, leading to a series of recent advances including the development of efficient emitters for organic LEDs that will lower their cost, improvements in manufacturing efficiency of warm-white LEDs, and improvements in the efficiency of green and amber LEDs.[74] DOE estimates that the widespread use of LED lighting resulted in 1.1 quads (quadrillion British thermal units) of energy savings in 2017, saving US consumers $12 billion. DOE forecasts that LED use will continue to spread and will comprise 84 percent of lighting installations by 2035, resulting in total annual energy savings of 4.8 quads.[75]

B. Impacts on Small Business and Startups

Focusing on the impacts of federal R&D on small business and entrepreneurship, one recent study examined DOE's Small Business Innovation Research (SBIR) program.[76] Administered by multiple agencies, the SBIR program is a federal grants and contracts program that provides startups and small businesses funding to pursue R&D and catalyze commercialization. DOE's SBIR program has two stages: applicants may apply for a Phase I award of $150,000, and Phase I winners may then apply 9 months later for a Phase II award of $1 million paid out two to three years after Phase I. The study relied on a proprietary dataset of SBIR applications covering 7,436 small technology firms and $884 million in awards from 1983 to 2013.[77]

The study found that Phase I award recipients experience higher levels of success according to several measures, and the effect is not due to crowding out of private investment. In particular, a Phase I SBIR award increases a firm's subsequent patents by more than 30 percent, increases the chance of receiving venture capital (VC) investment from 10 percent to 19 percent (and increases the amount of money raised), nearly doubles the probability of positive revenue (and among those with positive revenue, increases revenue by 30 percent), and increases the probability of survival and either IPO or acquisition. The study found that Phase II grants have only a small positive effect on patents, which the author of the study attributed to "adverse selection" because Phase I award recipients who choose not to apply for Phase II awards disproportionately have VC funding.

> *"A Phase I SBIR award increases a firm's subsequent patents by more than 30 percent."*

The study found that an early-stage SBIR award is helpful not because it provides a kind of certification for investors but rather because it provides financing for prototyping work that would not otherwise be attainable. Lastly, the author found the effect is concentrated among clean

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[73] Department of Energy: Office of Energy Efficiency and Renewable Energy, "Solid-State Lighting: Program Impacts," available at https://www.energy.gov/eere/ssl/program-impacts.

[74] Department of Energy: Office of Energy Efficiency and Renewable Energy, "Solid-State Lighting: Research Highlights," available at https://www.energy.gov/eere/ssl/research-highlights.

[75] Department of Energy, "Energy Savings Forecast of Solid-State Lighting in General Illumination Applications," December 2019, available at https://www.energy.gov/eere/ssl/downloads/2019-ssl-forecast-report.

[76] Sabrina Howell, "Financing Innovation: Evidence from R&D Grants," *American Economic Review*, Vol. 107(4), pp. 1136-64, April 2017.

[77] Similar to the study on NIH funding rules referenced above (see footnote 47), this study utilized discontinuities in the SBIR award rules to identify the impact of the awards on recipients.

energy technology firms, noting “no measurable effect for conventional energy technologies, like natural gas and coal, suggesting that they are not as financially constrained.”

Other research examined the impact of public R&D on private sector capital investment (including tangible assets such as buildings and equipment and intangible assets such as R&D), based on a government program in Italy providing R&D grants to private firms.[78] The study found that grants given to small firms cause those firms to subsequently increase total investment by the size of the grant, with proportionate increases in both tangible and intangible assets. The study found no effect for large firms. The authors attributed the differing effects by firm size to liquidity constraints faced by small firms conducting R&D, which is consistent with evidence found in other studies.[79]

C. Short-Term Impacts on Employment and the Workforce

Regarding the short-term economic impacts of public R&D investment, one standard method to estimate short-term economic impacts is input-output modeling, which relates the inputs and outputs of each industry to that of all other industries throughout the economy. Using this approach, a recent study estimated that NIH extramural research funding of $31 billion in fiscal year 2019 supported about 476,000 jobs throughout the United States, with the largest concentration of jobs in California (73,000 jobs), Massachusetts (37,000 jobs), and New York (36,000 jobs).[80] The analysis accounted for direct impacts of research-performing companies, indirect impacts of suppliers to those companies, and induced impacts of expenditures of labor income earned by employees of research-performing companies and their suppliers.[81]

> *“On average, each $1 million in ARRA R&D investment generated nearly 27 jobs in counties that received ARRA R&D grants.”*

A recent working paper examined the short-term economic impact of the R&D stimulus spending contained in the 2009 American Recovery and Reinvestment Act (ARRA), using a county-level econometric analysis of changes in employment over the five-year period (2009-2013) in which ARRA funds were disbursed.[82] ARRA R&D spending amounted to $26 billion over the period 2009 to 2013, primarily through grants from the Department of Energy,

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[78] Raffaello Bronzini and Eleonora Iachini, “Are Incentives for R&D Effective? Evidence from a Regression Discontinuity Approach,” *American Economic Journal: Economic Policy*, Vol. 6, pp. 100-134, 2014.

[79] For example, a recent study of R&D subsidies in the UK found that direct grants and tax credits are complementary for small firms in that both measures lead to increases in R&D expenditures, and yet are substitutes for large firms. See Jacqueline Pless, “Are 'Complementary Policies' Substitutes? Evidence from R&D Subsidies in the UK,” MIT mimeo, 2019. See also Bronwyn H. Hall and Josh Lerner, “The Financing of R&D and Innovation,” NBER Working Paper 15325, 2009.

[80] Everett Ehrlich, “NIH’s Role in Sustaining the U.S. Economy: 2020 State-by-State Update,” United for Medical Research, February 2020, available at https://www.unitedformedicalresearch.org/wp-content/uploads/2019/04/NIHs-Role-in-Sustaining-the-US-Economy-FY19-FINAL-2.13.2020.pdf; Everett Ehrlich, “An Economic Engine: NIH Research, Employment, and the Future of the Medical Innovation Sector,” United for Medical Research, 2012, available at https://www.unitedformedicalresearch.org/wp-content/uploads/2012/07/UMR_Economic-Engine.pdf

[81] The estimates were produced using the Regional Input-Output Modeling System, or RIMS II, which is estimated by the US Bureau of Economic Analysis.

[82] Yulia Chhabra, Margaret C. Levenstein, and Jason Owen-Smith, “The Local Economic Impact of Science Spending” Evidence from the American Recovery and Reinvestment Act,” University of Michigan

NIH, and the National Science Foundation that were allocated based on scientific merit or capability to locales with existing research capacity. The study found that, over the period 2009 to 2013, on average each $1 million in ARRA R&D investment generated nearly 27 jobs in counties that received ARRA R&D grants. The study found that 23 of those 27 jobs were in the private sector and found no evidence of crowding out of private sector jobs. Analyzed in terms of job-years, the study found on average each $1 million in ARRA R&D investment created 66 job-years at a cost of about $15,000 per job-year.

Ross School of Business Working Paper No. 1383, April 2019, available at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3201136.

IV. Economic Impact of Federal R&D in 2018

This section presents our estimates of the economic impact of the US federal government's investment in R&D at the national and state level in calendar year 2018. These estimates consider federally funded expenditures for R&D operations, plant, and equipment within the 50 states and the District of Columbia.

The total economic impact we have measured includes the ***direct impact*** (the jobs, labor income, value added, and tax payments directly attributable to *R&D performers*), the ***indirect impact*** (the jobs, labor income, value added, and tax payments attributable to *suppliers* to R&D performers), and the ***induced impact*** (the jobs, labor income, value added, and tax payments resulting from *household spending* of labor and proprietor's income earned either directly or indirectly from R&D performance).

To quantify these linkages, we rely on the IMPLAN model, an input-output (I-O) model based on government data.[83] For this analysis, we have separately quantified the indirect and induced impacts of federally funded **operational** and **capital spending** for R&D. Operating expenditures are the costs of non-capital inputs (such as labor, materials, rent, and utilities) for an entity (business or non-business) to run its operations on a daily basis. Capital expenditures are the amounts that entities use to invest in major physical goods or services that have a productive life of more than one year (i.e., R&D facilities and equipment).

Economic impacts are measured using four separate metrics: employment, labor income, value added, and tax payments, as defined below.

- **Employment**: The number of payroll and self-employed jobs (including part-time jobs), averaged over the year.
- **Labor income**: The wages, salaries and benefits paid to employees (and proprietors' income for the self-employed).
- **Value added**: The total output of a company or sector less the associated value of intermediate inputs. The sum of value added across all sectors in the economy is GDP.[84] A sector's value added represents its contribution to GDP.
- **Tax payments**: The taxes paid to federal, state and local governments, including income and non-income taxes.

A. Federal R&D Expenditures

As a first step, this section describes our estimates of federal R&D investment in 2018, consisting of federally funded expenditures for R&D operations, plant, and equipment within the 50 states and the District of Columbia, according to data provided by the National Science Foundation (NSF). As shown in **Table 1**, below, federally funded expenditures for R&D operations, plant, and equipment within the 50 states and the District of Columbia amounted to $131.3 billion in 2018, of which $127.1 billion was for R&D operations and $4.2 billion was for R&D plant and equipment. The majority (63 percent) of operational expenditures were for research, consisting of $40.3 billion of basic research and $39.4 billion of applied research,

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[83] See **Appendix B** for a detailed description of data sources and methodology used throughout this section.

[84] Value added differs from gross output (or sales) because it excludes the value of intermediate goods that are embedded in the final sales of each industry.

while the remainder (37 percent) consisted of development expenditures amounting to $47.4 billion.

By performer, 29.1 percent of federally funded R&D in 2018 was performed intramurally, i.e., by the federal government, while another 17.4 percent was performed by federally funded R&D centers (FFRDCs), such as the DOE's 17 national labs. The remainder of federally funded R&D was performed by colleges and universities (28.6 percent), business (18.1 percent), other nonprofits (6.7 percent), and state and local governments (0.2 percent).

Looking at the components of R&D expenditures, the majority (59.1 percent) of federally funded basic research was performed by colleges and universities; for federally funded applied research, intramural (29.3 percent) and colleges and universities (26.7 percent) are the lead performing sectors; for federally funded development, intramural (38.3 percent) and business (35.5 percent) are the lead performers. A relatively large portion (43.9 percent) of federally funded R&D expenditures for plant and equipment is attributable to FFRDCs, followed by intramural (32.6 percent).

Table 1. Federally Funded Expenditures for R&D by Type of R&D and Performer, 2018

Performer	R&D Operational Expenditures				R&D Plant and Equipment	Total
	Basic Research	Applied Research	Develop-ment	Total		
Total ($millions)	$40,329	$39,430	$47,373	$127,132	$4,174	$131,306
Federal intramural	17.1%	29.3%	38.8%	29.0%	32.6%	29.1%
Federally Funded R&D Centers	10.3%	21.0%	18.0%	16.5%	43.9%	17.4%
Nonfederal government	0.1%	0.5%	0.0%	0.2%	0.0%	0.2%
Business	4.3%	12.3%	35.5%	18.4%	8.1%	18.1%
Higher education	59.1%	26.7%	5.9%	29.2%	10.7%	28.6%
Other nonprofit institutions	9.2%	10.2%	1.8%	6.7%	4.7%	6.7%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Source: National Science Foundation (NSF) and PwC calculations.

Notes: Dollar amounts refer to federally funded expenditures for R&D in calendar year 2018, excluding federally funded R&D performed in US territories. Expenditures for R&D plant and equipment are estimated using NSF data on federal outlays for R&D operations, plant, and equipment in FY 2018. The distribution of R&D operational expenditures by performer relies on NSF data on federally funded expenditures for R&D in calendar year 2018. The distribution of R&D plant and equipment expenditures by performer relies on NSF data on federal obligations for R&D plant and equipment by performer in FY 2018; since federal obligations in a given year differ from federal outlays, the distribution of expenditures across performing entities are an estimate. Details may not add to totals due to rounding.

Table 2, below, shows the distribution of federal R&D investment by sector and state in 2018. Federal R&D investment by sector at the national and state level is estimated using NSF data on federal R&D spending by agency and state in 2017 and 2018, the Department of Energy (DOE) budget state tables for FY 2018, and DOE information on Advanced Research Projects Agency – Energy (ARPA-E) awards by state in calendar year 2018. Federal R&D investment in the defense sector, consisting of R&D expenditures by the Department of Defense and defense-related R&D expenditures by the DOE Office of Science, amounted to $57.7 billion in 2018. Federal R&D investment in the energy sector, consisting of energy-related R&D expenditures by the DOE, amounted to $9.5 billion in 2018. Federal R&D investment in the health sector, consisting of R&D expenditures by the Department of Health and Human Services, amounted to $36.1 billion in 2018. Federal R&D investment in all other sectors amounted to $28.0 billion in 2018.

The federal government funded R&D in every state in 2018, with 25 states seeing more than $1 billion in funding. Nonetheless, federal R&D funding was concentrated in a few states with national labs and other research centers. California, which has three national labs (Lawrence Livermore, Lawrence Berkeley, and SLAC National Accelerator), was the top state for federally funded R&D investment at $21.3 billion in 2018, primarily related to defense R&D. Maryland researchers received the second most federal R&D funding at $18.1 billion, mainly due to health sector R&D performed intramurally by NIH. Massachusetts received $7.1 billion in federal R&D funding mainly related to health sector R&D. New Mexico, home of Los Alamos and Sandia national labs, received $6.5 billion in federal R&D funding, most of which was defense related. Other top states for federal R&D investment were New York ($6.1 billion), Virginia, ($5.6 billion), and Alabama ($4.8 billion).[85]

> *"The federal government funded R&D in every state in 2018, with 25 states seeing more than $1 billion in funding."*

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[85] See **Appendix A** for the distributions by state of the components of federal R&D investment: (i) federal R&D operational expenditures (**Table A-1**) and (ii) federal expenditures for R&D plant and equipment (**Table A-2**). For instance, **Table A-2** shows that Tennessee and Illinois are among the top four states in terms of federal expenditures for R&D plant and equipment, owing in part to the presence of national labs in those states (Oak Ridge in Tennessee; Argonne and Fermi National Accelerator labs in Illinois).

Table 2. Composition of Federal R&D Investment by Sector and State, 2018

(Millions of dollars)

	Defense	Energy	Health	Other	All Sectors
US Total	**$57,691**	**$9,539**	**$36,073**	**$28,003**	**$131,306**
Alabama	$4,107	$30	$305	$386	$4,828
Alaska	$66	$7	$9	$116	$197
Arizona	$1,274	$12	$243	$347	$1,876
Arkansas	$47	$3	$43	$72	$164
California	$8,770	$2,295	$4,387	$5,826	$21,278
Colorado	$838	$520	$196	$1,542	$3,096
Connecticut	$1,917	$21	$560	$287	$2,785
Delaware	$25	$10	$46	$84	$166
District of Columbia	$2,589	$849	$133	$1,070	$4,641
Florida	$2,202	$22	$653	$972	$3,849
Georgia	$534	$28	$824	$448	$1,834
Hawaii	$188	$1	$44	$110	$343
Idaho	$107	$474	$8	$50	$639
Illinois	$1,532	$1,290	$786	$495	$4,103
Indiana	$302	$26	$265	$269	$861
Iowa	$250	$115	$304	$290	$959
Kansas	$49	$7	$138	$119	$314
Kentucky	$42	$18	$310	$107	$477
Louisiana	$67	$3	$171	$166	$407
Maine	$26	$3	$90	$70	$189
Maryland	$4,169	$45	$9,514	$4,418	$18,146
Massachusetts	$2,642	$89	$3,180	$1,150	$7,061
Michigan	$752	$75	$770	$386	$1,983
Minnesota	$320	$18	$598	$211	$1,146
Mississippi	$325	$1	$39	$171	$536
Missouri	$1,269	$33	$788	$226	$2,316
Montana	$30	$5	$72	$90	$197
Nebraska	$16	$12	$179	$133	$340
Nevada	$139	$2	$13	$26	$181
New Hampshire	$411	$5	$149	$131	$696
New Jersey	$1,435	$164	$199	$302	$2,101
New Mexico	$5,312	$575	$175	$388	$6,450
New York	$2,226	$486	$2,619	$815	$6,146
North Carolina	$284	$30	$1,723	$555	$2,593
North Dakota	$1	$9	$23	$88	$121
Ohio	$2,141	$48	$561	$494	$3,244
Oklahoma	$127	$10	$73	$231	$441
Oregon	$88	$8	$374	$361	$831
Pennsylvania	$1,647	$64	$1,522	$397	$3,630
Rhode Island	$404	$2	$180	$92	$678
South Carolina	$348	$63	$188	$128	$727
South Dakota	$17	$2	$26	$48	$92
Tennessee	$1,293	$1,215	$384	$421	$3,313
Texas	$1,227	$34	$840	$1,764	$3,866
Utah	$827	$5	$237	$162	$1,230
Vermont	$9	$3	$47	$41	$100
Virginia	$4,100	$42	$311	$1,139	$5,591
Washington	$1,129	$496	$1,186	$479	$3,291
West Virginia	$4	$171	$18	$20	$214
Wisconsin	$64	$76	$557	$278	$974
Wyoming	$4	$17	$14	$33	$68

Source: National Science Foundation; US Department of Energy; PwC calculations.

Notes: Dollar amounts refer to federally funded expenditures for R&D operations, plant, and equipment in calendar year 2018, excluding federally funded R&D performed in US territories. Details may not add to totals due to rounding.

B. National Impacts

Turning to the estimated economic impacts of federal R&D investment in 2018, **Table 3**, below, shows the direct, indirect, and induced impacts on the US economy in terms of employment, labor income (including wages, salaries and benefits as well as proprietors' income), value added, and tax payments. In 2018, federal funding of R&D directly provided 445,800 jobs for American workers; paid $50.9 billion in wages, salaries, fringe benefits, and proprietors' income; and generated $70.6 billion in GDP and $13.0 billion in tax payments to federal, state, and local governments. Including direct, indirect, and induced effects from operational and capital spending, federal R&D investment in 2018 supported 1.6 million jobs, $125.5 billion of labor income, $196.7 billion in value added, and $38.9 billion in tax payments.

> *"Including direct, indirect, and induced effects from operational and capital spending, federal R&D investment in 2018 supported 1.6 million jobs, $125.5 billion of labor income, $196.7 billion in value added, and $38.9 billion in tax payments."*

The economic multiplier, which represents the ratio of the *total* economic impact of federal R&D investment to the *direct* impact, ranges between 2.5 (for labor income) to 3.7 (for employment). An employment multiplier of 3.7 means that for each direct job generated by federal R&D investment another 2.7 jobs are supported throughout the rest of the economy.

The employment generated by federal R&D investment pays higher wages than the average job in the economy. For federally funded R&D jobs, average compensation per direct job is about $114,000 in 2018 – 83 percent higher than the overall economy average compensation of about $62,000. Including direct, indirect, and induced employment in sectors ranging from agriculture to manufacturing to retail, average labor income per federally funded R&D job is about $77,000, or 24 percent higher than the average for the overall economy.

> *"For federally funded R&D jobs, average compensation per direct job is about $114,000 in 2018 – 83 percent higher than the overall economy average compensation of about $62,000."*

Federally funded R&D jobs are also highly productive. The direct value added (contribution to GDP) per federally funded R&D job is over $158,000 in 2018, compared to about $103,000 for the overall economy.

Table 3. Economic Impacts of Federal R&D Investment on the US Economy, 2018

	Direct Impacts	Indirect Impacts	Induced Impacts	Total Impacts	Total / Direct (“Multiplier”)[d]
Employment (thousands of jobs)[a]	445.8	437.3	745.6	1,628.7	3.7
Labor Income ($billions)[b]	$50.9	$33.4	$41.2	$125.5	2.5
Value Added ($billions)	$70.6	$54.8	$71.2	$196.7	2.8
Tax Impact ($billions)[c]	$13.0	$10.5	$15.4	$38.9	3.0

Source: PwC calculations using the IMPLAN modeling system (2018 database).
Note: Details may not add to totals due to rounding.
[a] Employment is defined as the number of payroll and self-employed jobs, including part-time jobs.
[b] Labor income is defined as wages and salaries and benefits as well as proprietors’ income.
[c] Taxes include federal and state and local income and non-income taxes.
[d] Economic multiplier represents the overall (direct, indirect, and induced) impact relative to the direct impact.

Table 4, below, shows the direct and total economic impacts of federal R&D investment by sector. Federal funding of defense R&D directly provided 199,200 jobs, paid $22.5 billion in labor income, and generated $30.7 billion in GDP and $5.7 billion in tax payments in the United States in 2018. Including direct, indirect, and induced effects from operational and capital spending, federal R&D investment in the defense sector supported 701,000 jobs, $53.8 billion of labor income, $83.7 billion in value added, and $16.6 billion in tax payments.

The federal government’s R&D investment in the energy sector directly contributed 31,500 jobs, $3.6 billion in labor income, $5.0 billion in value added, and $0.9 billion in tax payments to the national economy in 2018. Including direct, indirect, and induced effects, federal R&D investment in the energy sector supported 112,100 jobs, $8.9 billion of labor income, $13.9 billion in value added, and $2.8 billion in tax payments.

Federal funding of health R&D directly generated 121,200 jobs, $14.0 billion in labor income, $19.8 billion in value added, and $3.7 billion in tax payments in the United States in 2018. Including direct, indirect, and induced effects, federal R&D investment in the health sector supported 449,200 jobs, $34.9 billion of labor income, $55.2 billion in value added, and $11.0 billion in tax payments.

Table 4. Direct and Total Impacts of Federal R&D Investment on the US Economy by Sector, 2018

Item	Direct Impacts	Total Impacts
Defense Sector		
Employment (thousands of jobs)[a]	199.2	701.0
Labor Income ($billions)[b]	$22.5	$53.8
Value Added ($billions)	$30.7	$83.7
Tax Impact ($billions)[c]	$5.7	$16.6
Energy Sector		
Employment (thousands of jobs)[a]	31.5	112.1
Labor Income ($billions)[b]	$3.6	$8.9
Value Added ($billions)	$5.0	$13.9
Tax Impact ($billions)[c]	$0.9	$2.8
Health Sector		
Employment (thousands of jobs)[a]	121.2	449.2
Labor Income ($billions)[b]	$14.0	$34.9
Value Added ($billions)	$19.8	$55.2
Tax Impact ($billions)[c]	$3.7	$11.0
Other		
Employment (thousands of jobs)[a]	94.0	366.4
Labor Income ($billions)[b]	$10.8	$27.8
Value Added ($billions)	$15.1	$43.9
Tax Impact ($billions)[c]	$2.8	$8.5

Source: PwC calculations using the IMPLAN modeling system (2018 database).
Note: Details may not add to totals due to rounding.
[a] Employment is defined as the number of payroll and self-employed jobs, including part-time jobs.
[b] Labor income is defined as wages and salaries and benefits as well as proprietors' income.
[c] Taxes include federal and state and local income and non-income taxes.

C. State Impacts

The economic impact of federal R&D investment at the state level reflects the indirect and induced effects attributable to direct activity within each state's borders, as well as indirect and induced activity within a state that is attributable to direct activity in other states.[86]

The economic impact of federal R&D investment varies from state to state, depending on factors such as each state's population, R&D expertise and research capacity, industry mix, wage structure, spending and saving patterns, and connections to other economies. In terms of direct impacts of federal R&D investment, **Figures 6**, **7**, and **8**, below, present employment, labor income, and value added for the top 15 states ranked by direct impacts (details for all states are available in **Appendix A**).

The figures indicate that California and Maryland rank substantially above all other states in terms of direct impacts of federal R&D investment in 2018, with about 55,000 jobs, $9.2 billion of labor income, and $13.6 billion of value added contributed in California and about 60,000 jobs, $7.4 billion of labor income, and $10.0 billion of value added contributed in Maryland.

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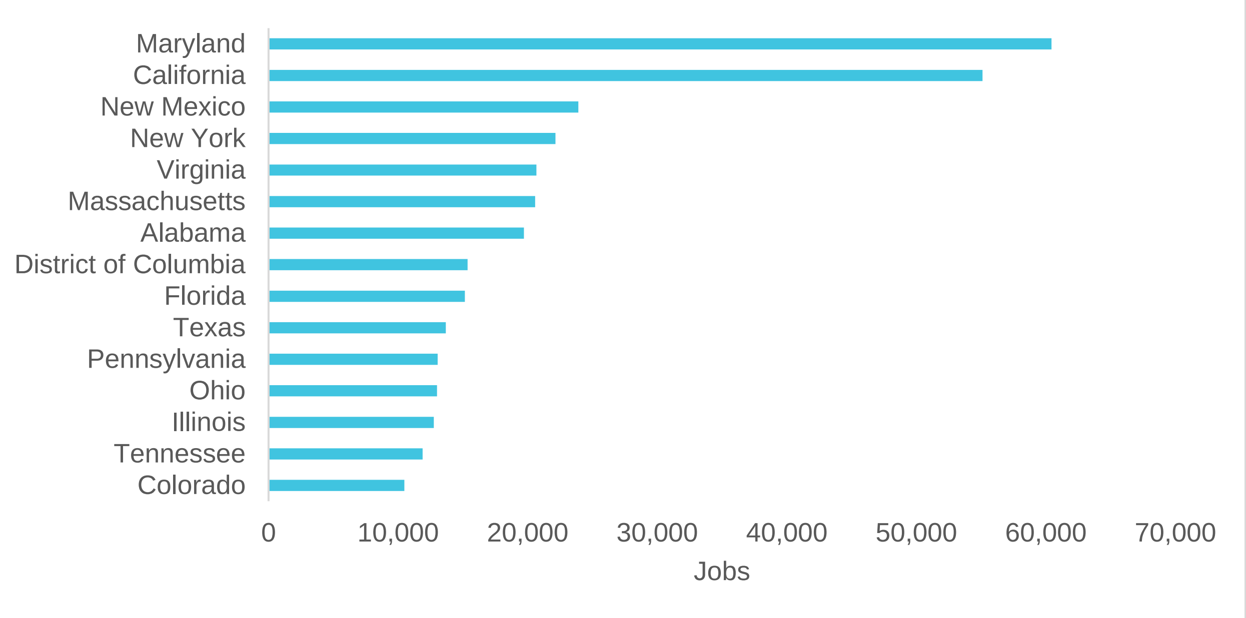
[86] We have allocated the indirect and induced effects by industry attributable to direct activity in other states based on the overall level of economic activity of that industry in each state.

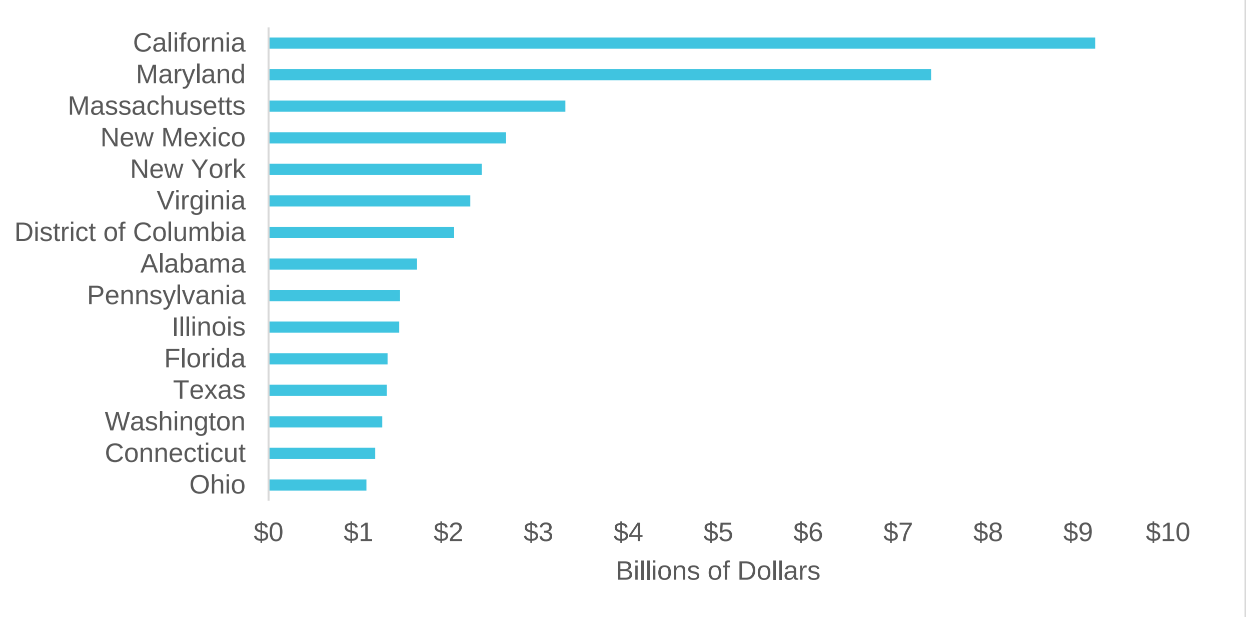
California's direct impacts are attributable in part to the three national labs located there as well as multiple research universities, while Maryland's direct impacts are partly attributable to the presence of NIH in Bethesda. Other states with exceptionally large direct impacts include New Mexico, New York, Virginia, Massachusetts, and Alabama, each with about 20,000 to 24,000 jobs directly attributable to federal R&D investment. These states are home to major research centers, e.g., the Los Alamos and Sandia national labs in New Mexico and the complex of Department of Defense and NASA labs located in Huntsville, Alabama.

Figure 6. The Direct Impact of Federal R&D Investment: Top 15 States by Direct Employment, 2018



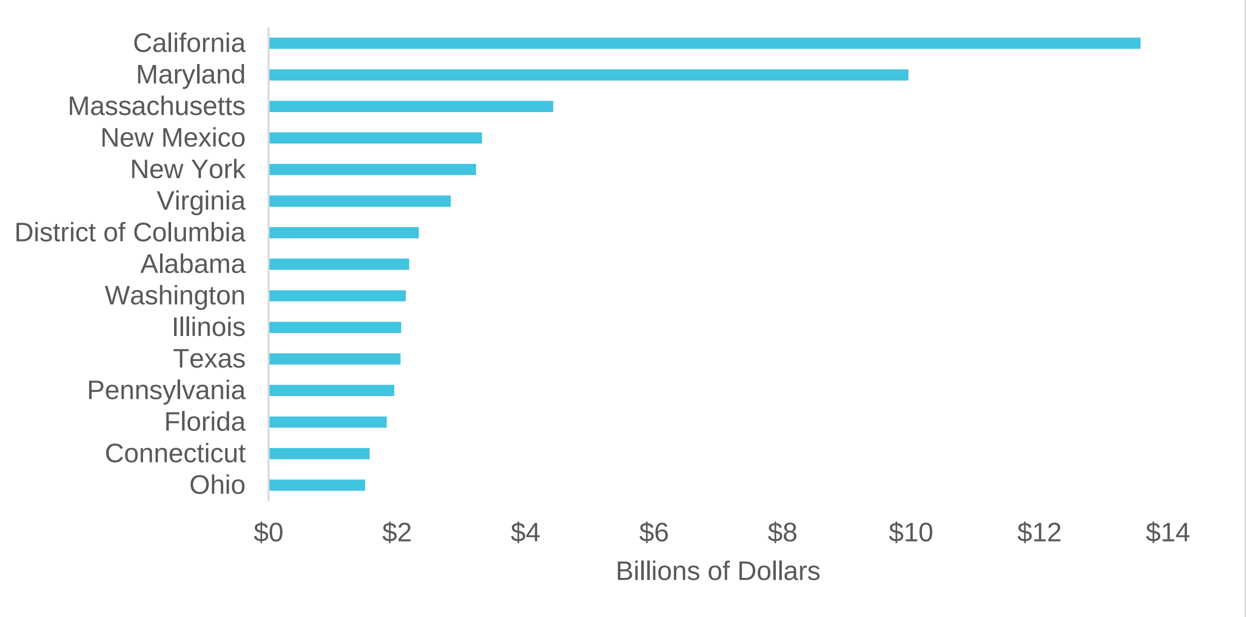
Source: PwC calculations based on the IMPLAN model. See Appendix A for underlying data.

**Figure 7. The Direct Impact of Federal R&D Investment:
Top 15 States by Direct Labor Income, 2018**



Source: PwC calculations based on the IMPLAN model. See Appendix A for underlying data.

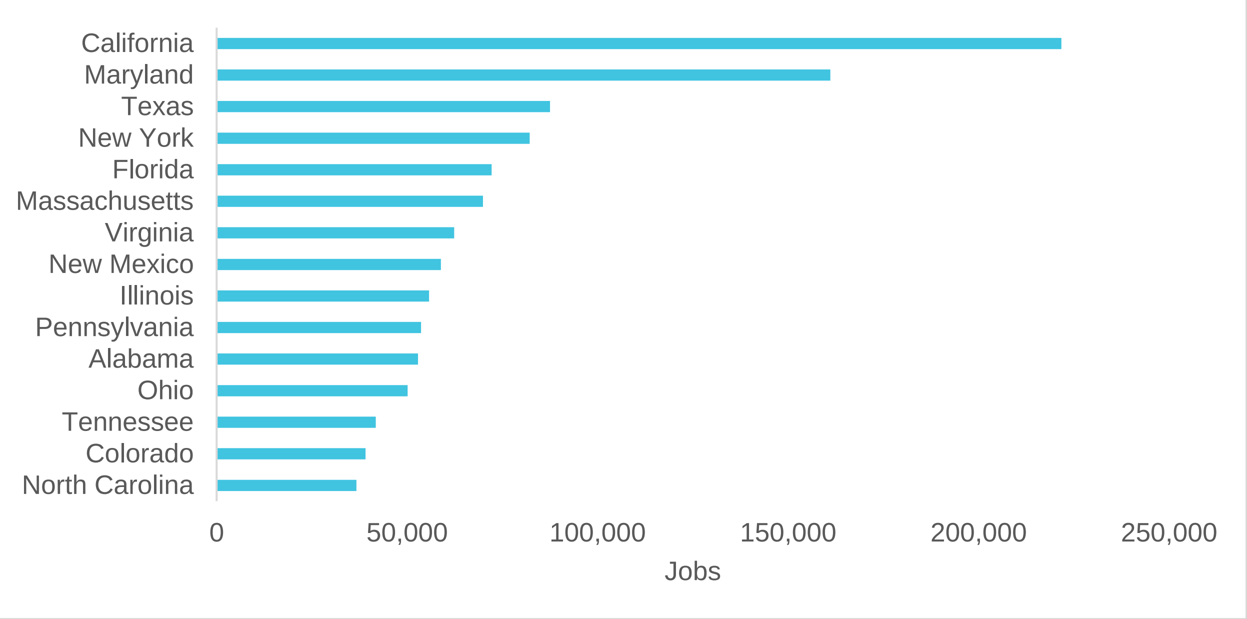
**Figure 8. The Direct Impact of Federal R&D Investment:
Top 15 States by Direct Value Added, 2018**



Source: PwC calculations based on the IMPLAN model. See Appendix A for underlying data.

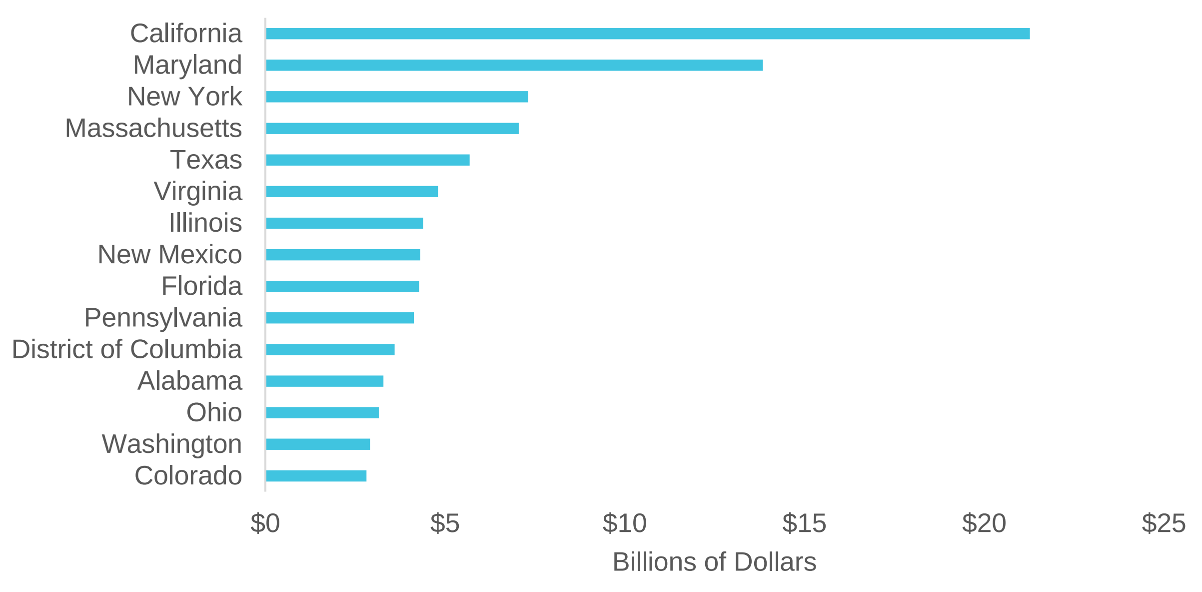
Figures 9, **10**, and **11**, below, present the total impact of federal R&D investment by state, including direct, indirect, and induced impacts. Looking at the top 15 states in terms of total employment supported by federal R&D investment, **Figure 9**, below, indicates that California and Maryland rank highest by this measure as well, with 222,000 and 161,000 jobs, respectively. Other states ranking high by this measure include Texas, New York, Florida, Massachusetts, and Virginia. These states also rank high in terms of labor income and value added supported by federal R&D investment (see **Figures 10** and **11**, below). These states have high total impacts from federal R&D investment in part because they have major research centers (and therefore have high direct impacts) and in part because they are among the largest economies in the country (and therefore have high indirect and induced impacts). (**Appendix A** additionally reports impacts in per capita amounts and as a share of each state's economy.

Figure 9. The Total Impact of Federal R&D Investment:
Top 15 States by Total Employment, 2018



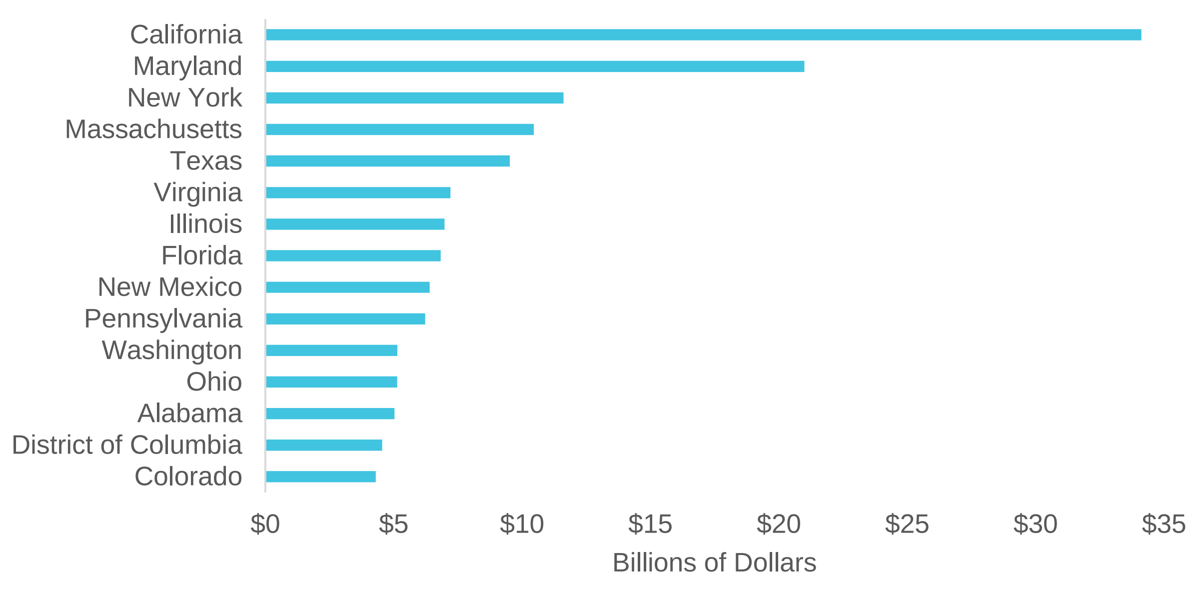
Source: PwC calculations based on the IMPLAN model. See Appendix A for underlying data.

Figure 10. The Total Impact of Federal R&D Investment: Top 15 States by Total Labor Income, 2018



Source: PwC calculations based on the IMPLAN model. See Appendix A for underlying data.

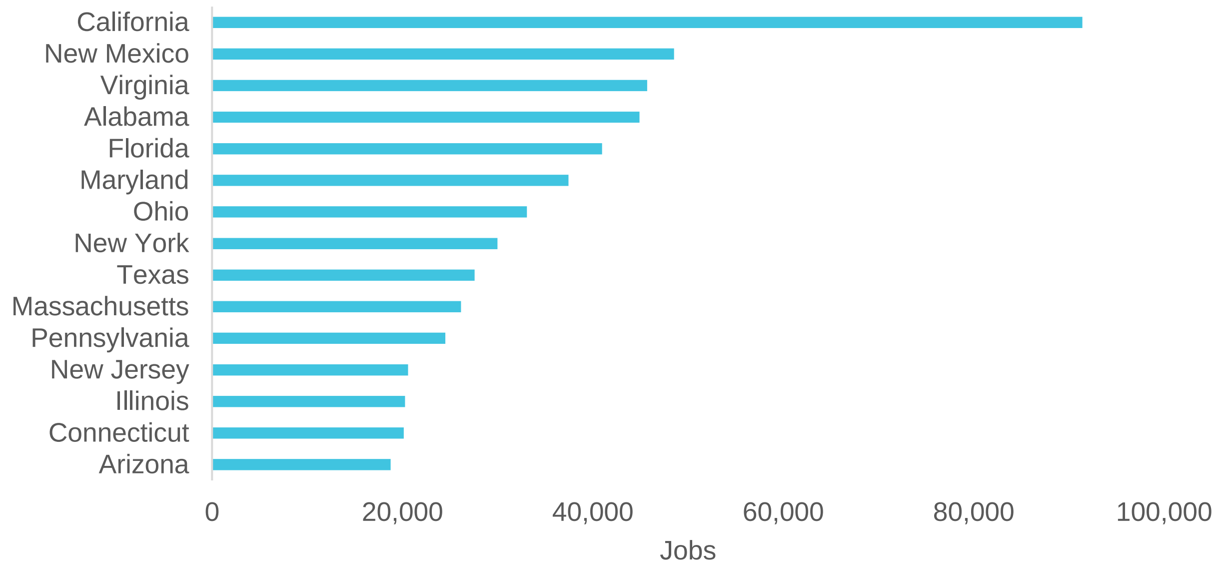
Figure 11. The Total Impact of Federal R&D Investment: Top 15 States by Total Value Added, 2018



Source: PwC calculations based on the IMPLAN model. See Appendix A for underlying data.

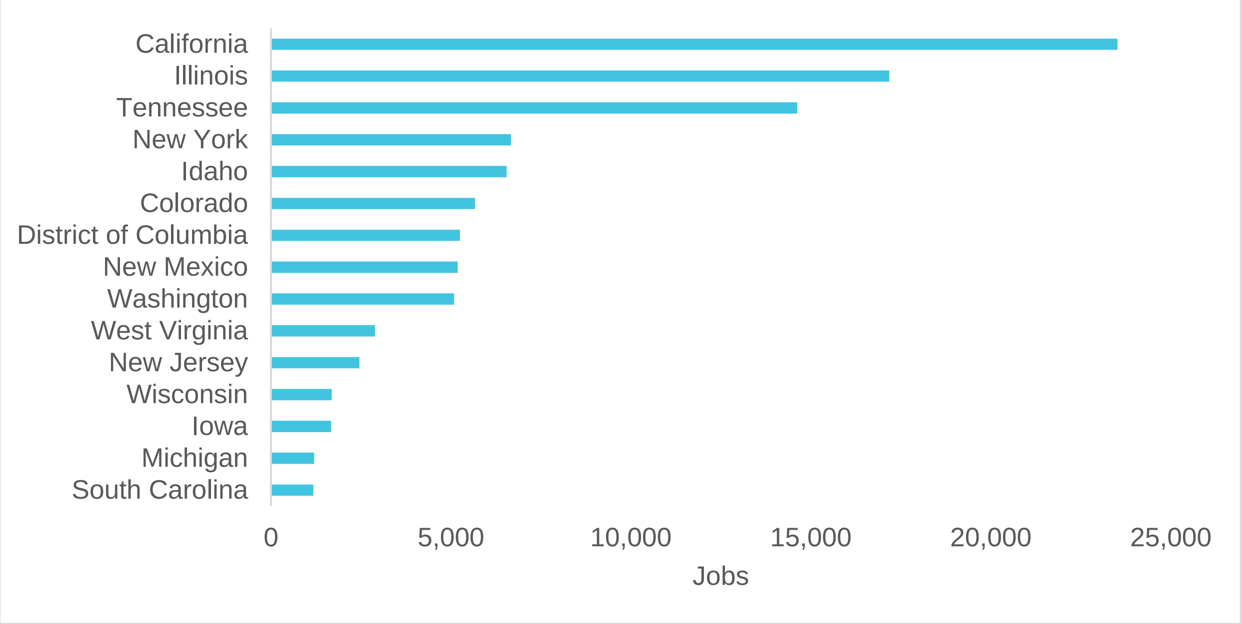
Figures 12, **13**, and **14**, below, present the total employment impact (including direct, indirect, and induced impacts) of federal R&D investment by state for the defense, energy, and health sectors. Looking at the top 15 states in terms of total employment attributable to federal R&D investment in the defense sector, **Figure 12**, below, indicates that California ranks highest by this measure as well, with 91,000 jobs, followed by 49,000 jobs in New Mexico, 46,000 jobs in Virginia, and 45,000 jobs in Alabama. **Figure 13**, below, indicates that California also ranks highest in terms of total employment attributable to federal R&D investment in the energy sector, with 24,000 jobs, followed by 17,000 jobs in Illinois and 15,000 jobs in Tennessee. **Figure 14**, below, indicates that Maryland ranks highest in terms of total employment attributable to federal R&D investment in the health sector with 85,000 jobs, followed by 46,000 jobs in California and 35,000 jobs in New York.

Figure 12. The Total Impact of Federal R&D Investment in the Defense Sector: Top 15 States by Total Employment, 2018



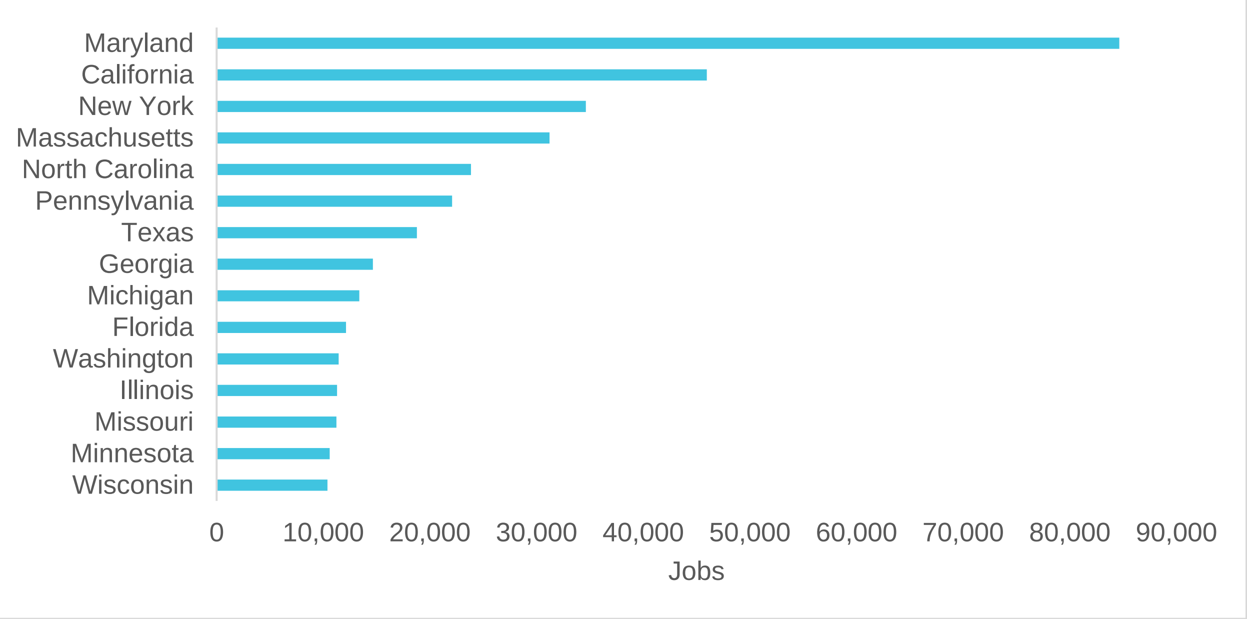
Source: PwC calculations based on the IMPLAN model. See Appendix A for underlying data.

Figure 13. The Total Impact of Federal R&D Investment in the Energy Sector: Top 15 States by Total Employment, 2018



Source: PwC calculations based on the IMPLAN model. See Appendix A for underlying data.

Figure 14. The Total Impact of Federal R&D Investment in the Health Sector: Top 15 States by Total Employment, 2018



Source: PwC calculations based on the IMPLAN model. See Appendix A for underlying data.

V. Impacts of Expanded Federal R&D Investments, 2021-2030

This section presents the potential economic impacts of federal R&D investment at the national level projected through 2030 under a scenario of increased federal funding over the next 10 years such that federal R&D investment grows from 0.6 percent of GDP in 2018 to 1.0 percent of GDP in 2030 – approaching the average level of federal R&D investment observed since 1953.[87] Such a sustained investment in R&D would support a steady stream of jobs and other economic benefits and potentially lead to more broadly shared long-term economic benefits due to the accumulation of knowledge and technological innovation.

Figure 15, below, illustrates the pattern of federal R&D investment under this scenario. Beginning with federal R&D investment of $131.3 billion in 2018, we assume nominal federal R&D investment in 2019 grows 9.9 percent to $144.3 billion and in 2020 grows 7.4 percent to $155.0 billion, based on preliminary estimates and projections of the growth in federal R&D outlays according to the NSF and CBO.[88] We then assume nominal federal R&D investment is boosted 14.7 percent to $177.9 billion in 2021 (approximately twice the rate of growth in 2020), followed by a sustained annual nominal growth rate of 6.6 percent through 2030. This results in federal R&D investment of $315.5 billion in 2030, which is 1 percent of projected GDP that year (according to the CBO) and amounts to slightly more than a doubling (103 percent) in nominal terms of federal R&D investment over the period 2020 to 2030.[89]

A short-term boost in federal R&D spending could provide economic stimulus to address the economic crisis caused by COVID-19 and support employment opportunities both directly and indirectly for researchers and others who have been or will be laid off due to budget cuts by businesses, state and local governments, academic institutions, and non-profits. The CBO forecasts that unemployment will remain above 7 percent through 2021.[90]

A long-term sustained increase in federal R&D spending could reverse the observed decline in federal R&D investment as a share of GDP since the 1960s (see **Figure 2**, above). It may also serve to address the chronic slow-down in productivity growth that has occurred over this period as well.[91] In addition, it may serve to offset COVID-19-related productivity losses at research labs as well as the loss of innovative startups due to tightening capital markets. Lastly, by providing a sustained increase in federal R&D investment, it is more likely that labor market

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[87] Federally funded R&D operational expenditures average 1.06 percent of GDP from 1953 to 2018. The historical data do not include expenditures for R&D plant and equipment. However, the data do include a roughly offsetting amount from 1953 to 2015 for expenditures for preproduction development, due to a definitional change (see note to Figure 2, above). National Science Foundation, *National Patterns of R&D Resources: 2017-18 Data Update,* NSF 20-307, Table 1, January 8, 2020, available at https://www.nsf.gov/statistics/natlpatterns/.

[88] National Science Foundation, *Survey of Federal Funds for Research and Development: Fiscal Years 2018-19,* Table 2, January 2020, available at https://ncsesdata.nsf.gov/fedfunds/2018/; Congressional Budget Office, *Spending Projections, by Budget Account*, data that supplement CBO's March 2020 report *Baseline Budget Projections as of March 6, 2020*, available at https://www.cbo.gov/publication/56268.

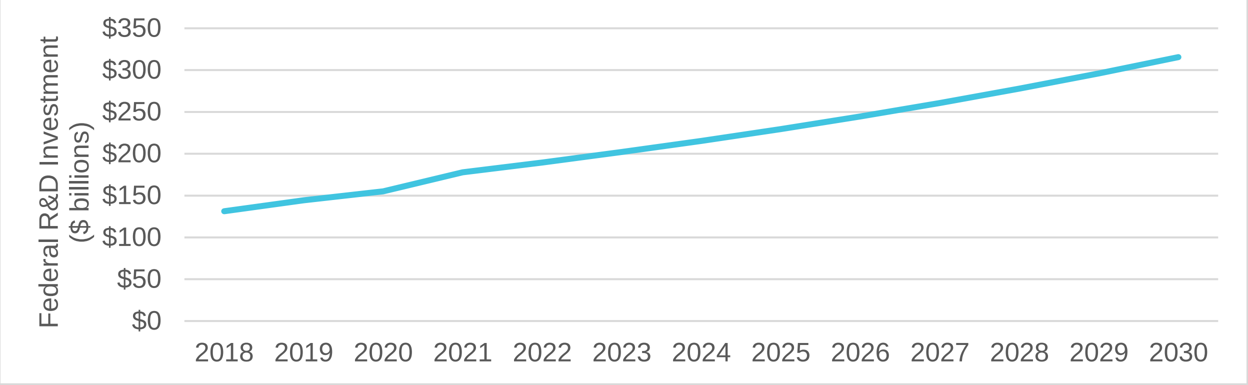
[89] Congressional Budget Office, *An Update to the Economic Outlook: 2020 to 2030*, July 2020, available at https://www.cbo.gov/publication/56465.

[90] Ibid.

[91] Lew Sveikauskas, "R&D and Productivity Growth: A Review of the Literature," US Bureau of Labor Statistics, Working Paper 408, September 2007, available at: https://www.bls.gov/osmr/research-papers/2007/pdf/ec070070.pdf.

resources and institutions, e.g., university and training programs, can adjust in an efficient manner to the number and types of research scientists that are required.[92]

Figure 15. Possible Expansion of Federal R&D Investment, 2018-2030



Source: National Science Foundation; Congressional Budget Office; PwC calculations.
Notes: Dollar amounts refer to nominal federally funded expenditures for R&D operations, facilities and equipment, excluding federally funded R&D performed in US territories.

Using the IMPLAN modeling system to quantify the short-term economic impacts of this scenario's increase in federal R&D investment through 2030, **Tables 5**, **6**, and **7**, below, show the direct, indirect, and induced impacts on the US economy in terms of employment, labor income (including wages, salaries, and benefits as well as proprietors' income), value added, and tax payments. Under this scenario, in 2021, federal funding of R&D directly provides 569,400 jobs for American workers; pays $67.9 billion in wages, salaries, fringe benefits, and proprietors' income; and generates $96.9 billion in GDP and $17.6 billion in tax payments to federal, state, and local governments. Including direct, indirect, and induced effects from operational and capital spending, federal R&D investment supports 2.1 million jobs, $170.4 billion of labor income, $271.0 billion in value added, and $46.0 billion in tax payments.

Under this scenario in 2030, federal funding of R&D directly provides 892,000 jobs, pays $120.5 billion in labor income, and generates $171.9 billion in GDP and $31.2 billion in tax payments in the United States. Including direct, indirect, and induced effects from operational and capital spending, federal R&D investment supports 3.4 million jobs, $301.2 billion of labor income, $478.0 billion in value added, and $81.4 billion in tax payments.

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[92] William Alan Reinsch, Jonathan Lesh, Lydia Murray, and John Hoffner, "Taking Stock of Government Involvement in Research and Development," Center for Strategic and International Studies, June 2020, available at https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/200602_Reinsch_R%26D_v2.pdf; Richard Freeman and John Van Reenen, "What If Congress Doubled R&D Spending on the Physical Sciences?," *Innovation Policy and the Economy*, Vol. 9, 2009, available at https://www.journals.uchicago.edu/doi/abs/10.1086/592419.

Over the entire period from 2021 to 2030 under this scenario, federal R&D investment directly contributes 719,200 annual jobs on average, and cumulatively over the 10-year period provides $919.6 billion in labor income, $1.3 trillion in value added, and $238.1 billion in tax payments to the national economy. Including direct, indirect, and induced effects, federal R&D investment supports 2.7 million annual jobs on average, and cumulatively supports $2.3 trillion of labor income, $3.7 trillion in value added, and $622.9 billion in tax payments over the 10-year period.

> *"Including direct, indirect, and induced effects, the assumed higher level of federal R&D investment supports 2.7 million annual jobs on average, and cumulatively supports $2.3 trillion of labor income, $3.7 trillion in value added, and $622.9 billion in tax payments over 2021-2030."*

Table 5. Economic Impacts of Federal R&D on the US Economy with Possible Expansion, 2021

	Direct Impacts	Indirect Impacts	Induced Impacts	Total Impacts
Employment (thousands of jobs)[a]	569.4	568.2	1,005.1	2,142.7
Labor Income ($billions)[b]	$67.9	$44.8	$57.7	$170.4
Value Added ($billions)	$96.9	$74.3	$99.7	$271.0
Tax Impact ($billions)[c]	$17.6	$14.2	$14.3	$46.0

Source: PwC calculations using the IMPLAN modeling system (2018 database).

Notes: All dollar amounts are in nominal terms. Nominal federal R&D investment is assumed to increase by 14.7 percent in 2021 from 2020. Details may not add to totals due to rounding.

[a] Employment is defined as the number of payroll and self-employed jobs, including part-time jobs.

[b] Labor income is defined as wages and salaries and benefits as well as proprietors' income.

[c] Taxes include federal and state and local income and non-income taxes.

Table 6. Economic Impacts of Federal R&D on the US Economy with Possible Expansion, 2030

	Direct Impacts	Indirect Impacts	Induced Impacts	Total Impacts
Employment (thousands of jobs)[a]	892.0	890.2	1,574.5	3,356.7
Labor Income ($billions)[b]	$120.5	$79.3	$101.4	$301.2
Value Added ($billions)	$171.9	$130.9	$175.2	$478.0
Tax Impact ($billions)[c]	$31.2	$25.0	$25.2	$81.4

Source: PwC calculations using the IMPLAN modeling system (2018 database).

Notes: All dollar amounts are in nominal terms. Nominal federal R&D investment is assumed to increase by 103.5 percent in 2030 from 2020. Details may not add to totals due to rounding.

[a] Employment is defined as the number of payroll and self-employed jobs, including part-time jobs.

[b] Labor income is defined as wages and salaries and benefits as well as proprietors' income.

[c] Taxes include federal and state and local income and non-income taxes.

Table 7. Economic Impacts of Federal R&D on the US Economy with Possible Expansion, 2021-2030

	Direct Impacts	Indirect Impacts	Induced Impacts	Total Impacts
Employment (thousands of jobs)[a]: 10-year average	719.2	717.7	1,269.5	2,706.4
Labor Income ($billions)[b]	$919.6	$606.8	$778.1	$2,304.5
Value Added ($billions)	$1,312.7	$1,002.8	$1,344.2	$3,659.7
Tax Impact ($billions)[c]	$238.1	$191.7	$193.1	$622.9

Source: PwC calculations using the IMPLAN modeling system (2018 database).

Notes: All dollar amounts are in nominal terms. Nominal federal R&D investment is assumed to increase on an annual basis by 14.7 percent in 2021 and by 6.6 percent each year thereafter until 2030. Details may not add to totals due to rounding.

[a] Employment is defined as the number of payroll and self-employed jobs, including part-time jobs.

[b] Labor income is defined as wages and salaries and benefits as well as proprietors' income.

[c] Taxes include federal and state and local income and non-income taxes.

In the short term, federal R&D programs that address the immediate needs of the economy, particularly high unemployment or underemployment brought on by the COVID-19 pandemic and measures to contain it, may be particularly worthwhile. Such research may include an emphasis on health sector R&D. As highlighted in **Section III**, the early successes of NIH researchers on COVID-19 hold promise for near-term medical breakthroughs in the form of treatments, vaccines, and diagnostics for COVID-19 that would allow a return to more normal working conditions.

Over the long term, federal R&D investment can boost productivity and strengthen US economic competitiveness. Productivity gains can come from technological advancements related to defense, energy, health, or other sectors, and it is not clear that any one sector has clear advantages in this regard. Beyond economic productivity, additional social benefits may be realized from federal R&D investments that seek to address climate change, promote national security, and advance treatment and resilience to disease.

In sum, increasing federal funding of R&D over the next decade will support growth in US employment and income that bolsters the US economy's innovative capacity, potentially leading to major advancements in human health, clean energy, national defense, and other areas. These factors should be considered in weighing the benefits and costs of increasing federal R&D investment.

Appendix A: Detailed Results by State

Table A-1. Composition of Federal R&D Operational Expenditures by Sector and State, 2018 (Millions of dollars)

	Defense	Energy	Health	Other	All Sectors
US Total	**$56,275**	**$8,283**	**$35,832**	**$26,741**	**$127,132**
Alabama	$3,976	$29	$302	$382	$4,688
Alaska	$66	$6	$9	$98	$179
Arizona	$1,274	$11	$243	$330	$1,858
Arkansas	$47	$3	$41	$71	$162
California	$8,482	$1,955	$4,387	$5,732	$20,556
Colorado	$836	$354	$196	$1,417	$2,803
Connecticut	$1,916	$20	$560	$285	$2,781
Delaware	$25	$10	$46	$83	$164
District of	$2,506	$719	$133	$926	$4,284
Florida	$2,199	$21	$653	$888	$3,760
Georgia	$534	$26	$824	$437	$1,822
Hawaii	$186	$1	$44	$90	$322
Idaho	$107	$474	$8	$50	$639
Illinois	$1,303	$1,110	$786	$484	$3,682
Indiana	$301	$25	$265	$266	$856
Iowa	$248	$109	$304	$278	$939
Kansas	$39	$6	$138	$119	$302
Kentucky	$41	$18	$310	$105	$474
Louisiana	$50	$2	$171	$160	$383
Maine	$26	$3	$90	$70	$189
Maryland	$4,148	$43	$9,279	$4,149	$17,619
Massachusetts	$2,635	$85	$3,180	$1,140	$7,040
Michigan	$671	$55	$770	$378	$1,874
Minnesota	$319	$18	$598	$210	$1,145
Mississippi	$325	$1	$39	$154	$519
Missouri	$1,265	$33	$788	$225	$2,311
Montana	$30	$5	$72	$87	$194
Nebraska	$16	$12	$179	$132	$339
Nevada	$111	$1	$13	$26	$151
New	$411	$5	$149	$129	$694
New Jersey	$1,435	$147	$199	$266	$2,047
New Mexico	$5,243	$552	$175	$385	$6,354
New York	$2,159	$457	$2,619	$803	$6,038
North Carolina	$284	$29	$1,723	$547	$2,583
North Dakota	$1	$9	$23	$88	$121
Ohio	$2,140	$45	$561	$407	$3,153
Oklahoma	$127	$9	$73	$228	$437
Oregon	$88	$7	$374	$248	$716
Pennsylvania	$1,636	$62	$1,522	$390	$3,611
Rhode Island	$399	$2	$180	$76	$657
South Carolina	$343	$59	$188	$114	$704
South Dakota	$17	$2	$26	$47	$92
Tennessee	$1,081	$962	$384	$413	$2,839
Texas	$1,217	$32	$840	$1,700	$3,788
Utah	$827	$4	$237	$161	$1,229
Vermont	$9	$3	$47	$39	$98
Virginia	$3,982	$37	$311	$1,127	$5,457
Washington	$1,125	$466	$1,186	$474	$3,251
West Virginia	$4	$151	$18	$19	$192
Wisconsin	$64	$73	$557	$276	$969
Wyoming	$4	$17	$14	$32	$67

Source: National Science Foundation; US Department of Energy; PwC calculations.

Notes: Dollar amounts refer to federally funded operational expenditures for R&D in calendar year 2018, excluding federally funded R&D performed in US territories. Details may not add to totals due to rounding.

Table A-2. Composition of Federal R&D Expenditures for Plant and Equipment by Sector and State, 2018 (Millions of dollars)

	Defense	Energy	Health	Other	All Sectors
US Total	**$1,416**	**$1,255**	**$241**	**$1,262**	**$4,174**
Alabama	$132	$2	$3	$4	$140
Alaska	*	*	*	$18	$18
Arizona	*	*	*	$17	$18
Arkansas	*	*	$2	$1	$3
California	$288	$340	*	$94	$722
Colorado	$1	$167	*	$125	$294
Connecticut	$1	*	*	$2	$4
Delaware	*	*	*	$2	$2
District of	$83	$130	*	$144	$357
Florida	$3	$1	*	$84	$88
Georgia	*	$1	*	$11	$12
Hawaii	$2	*	*	$19	$21
Idaho	*	*	*	*	*
Illinois	$229	$180	*	$12	$421
Indiana	*	$1	*	$3	$5
Iowa	$2	$6	*	$11	$19
Kansas	$11	$1	*	$1	$12
Kentucky	*	$1	*	$2	$3
Louisiana	$17	*	*	$6	$23
Maine	*	*	*	*	$1
Maryland	$20	$2	$235	$269	$526
Massachusetts	$7	$4	*	$9	$20
Michigan	$81	$20	*	$8	$109
Minnesota	*	$1	*	$1	$1
Mississippi	*	*	*	$17	$17
Missouri	$4	$1	*	$1	$6
Montana	*	*	*	$3	$3
Nebraska	*	*	*	*	*
Nevada	$29	$1	*	*	$30
New	*	*	*	$2	$3
New Jersey	*	$18	*	$36	$54
New Mexico	$70	$22	*	$4	$96
New York	$67	$29	*	$13	$109
North Carolina	$1	$1	*	$8	$10
North Dakota	*	*	*	$1	$1
Ohio	$1	$3	*	$87	$91
Oklahoma	*	*	*	$3	$4
Oregon	*	*	*	$114	$114
Pennsylvania	$12	$1	*	$6	$19
Rhode Island	$5	*	*	$16	$21
South Carolina	$5	$4	*	$14	$23
South Dakota	*	*	*	*	$1
Tennessee	$212	$254	*	$8	$474
Texas	$11	$2	*	$65	$78
Utah	*	*	*	$1	$1
Vermont	*	*	*	$2	$2
Virginia	$118	$5	*	$11	$134
Washington	$4	$30	*	$6	$40
West Virginia	$1	$20	*	$1	$22
Wisconsin	*	$3	*	$2	$5
Wyoming	*	*	*	$1	$1

Source: National Science Foundation; US Department of Energy; PwC calculations.

Notes: Dollar amounts refer to federally funded expenditures for R&D plant and equipment in calendar year 2018, excluding R&D plant and equipment located in US territories. Details may not add to totals due to rounding. An asterisk (*) denotes less than $500,000.

Table A-3. Per Capita Federal R&D Investment by Sector and State, 2018

(Dollars)

	By Sector				Total
	Defense	Energy	Health	Other	
US Total	**$177**	**$29**	**$110**	**$86**	**$402**
Alabama	$840	$6	$62	$79	$988
Alaska	$90	$9	$12	$157	$268
Arizona	$178	$2	$34	$48	$262
Arkansas	$16	$1	$14	$24	$55
California	$222	$58	$111	$148	$539
Colorado	$147	$91	$34	$271	$544
Connecticut	$537	$6	$157	$80	$780
Delaware	$26	$11	$48	$87	$172
District of Columbia	$3,690	$1,210	$190	$1,526	$6,616
Florida	$104	$1	$31	$46	$181
Georgia	$51	$3	$78	$43	$174
Hawaii	$133	$1	$31	$77	$242
Idaho	$61	$271	$5	$29	$365
Illinois	$120	$101	$62	$39	$322
Indiana	$45	$4	$40	$40	$129
Iowa	$79	$36	$97	$92	$304
Kansas	$17	$2	$47	$41	$108
Kentucky	$9	$4	$69	$24	$107
Louisiana	$14	$1	$37	$36	$87
Maine	$19	$2	$67	$53	$141
Maryland	$691	$7	$1,576	$732	$3,006
Massachusetts	$384	$13	$462	$167	$1,026
Michigan	$75	$8	$77	$39	$199
Minnesota	$57	$3	$107	$38	$204
Mississippi	$109	*	$13	$57	$180
Missouri	$207	$5	$129	$37	$378
Montana	$28	$5	$68	$85	$186
Nebraska	$8	$6	$93	$69	$176
Nevada	$46	$1	$4	$9	$60
New Hampshire	$304	$4	$110	$97	$514
New Jersey	$162	$19	$22	$34	$236
New Mexico	$2,538	$275	$84	$186	$3,082
New York	$114	$25	$134	$42	$315
North Carolina	$27	$3	$166	$53	$250
North Dakota	$1	$12	$30	$116	$160
Ohio	$183	$4	$48	$42	$278
Oklahoma	$32	$2	$19	$59	$112
Oregon	$21	$2	$89	$86	$199
Pennsylvania	$129	$5	$119	$31	$284
Rhode Island	$382	$2	$170	$87	$641
South Carolina	$68	$12	$37	$25	$143
South Dakota	$19	$2	$29	$54	$105
Tennessee	$191	$179	$57	$62	$489
Texas	$43	$1	$29	$62	$135
Utah	$262	$1	$75	$51	$390
Vermont	$15	$4	$75	$65	$160
Virginia	$482	$5	$37	$134	$658
Washington	$150	$66	$158	$64	$437
West Virginia	$2	$95	$10	$11	$118
Wisconsin	$11	$13	$96	$48	$168
Wyoming	$8	$29	$24	$57	$118

Source: National Science Foundation; US Department of Energy; US Census Bureau; PwC calculations.
Notes: Dollar amounts refer to federally funded expenditures for R&D operations, plant, and equipment in calendar year 2018, excluding federally funded R&D performed in US territories. Details may not add to totals due to rounding. An asterisk (*) denotes less than $500,000.

Table A-4. The Economic Impact of Federal R&D Investment by State, 2018

(Dollar amounts in millions)

	Employment		Labor Income		Value Added		Tax Impact	
	Direct	Total	Direct	Total	Direct	Total	Direct	Total
US Total	**445,770**	**1,628,600**	**$50,932**	**$125,451**	**$70,639**	**$196,657**	**$13,030**	**$38,877**
Alabama	19,710	52,850	$1,650	$3,285	$2,190	$5,028	$371	$909
Alaska	780	2,470	$70	$171	$80	$273	$14	$47
Arizona	6,920	28,020	$660	$1,795	$981	$2,907	$163	$542
Arkansas	770	5,410	$47	$267	$64	$440	$11	$89
California	55,110	221,770	$9,191	$21,269	$13,572	$34,119	$2,458	$6,673
Colorado	10,480	39,080	$1,083	$2,816	$1,475	$4,298	$269	$836
Connecticut	9,530	29,490	$1,186	$2,640	$1,574	$3,988	$333	$869
Delaware	580	2,800	$74	$216	$90	$373	$18	$69
District of Columbia	15,360	29,550	$2,063	$3,597	$2,338	$4,553	$497	$959
Florida	15,160	72,180	$1,323	$4,280	$1,839	$6,831	$314	$1,359
Georgia	7,250	33,410	$635	$2,096	$902	$3,464	$150	$626
Hawaii	1,450	5,270	$127	$334	$139	$507	$28	$110
Idaho	2,550	8,840	$244	$539	$315	$808	$59	$157
Illinois	12,760	55,770	$1,454	$4,388	$2,065	$6,980	$377	$1,381
Indiana	2,810	15,640	$238	$951	$500	$1,764	$68	$298
Iowa	4,080	13,790	$293	$783	$423	$1,309	$72	$240
Kansas	1,280	7,200	$94	$404	$139	$667	$24	$128
Kentucky	2,190	10,520	$152	$562	$196	$890	$36	$181
Louisiana	1,750	9,770	$118	$523	$161	$954	$26	$169
Maine	850	3,950	$61	$211	$81	$332	$16	$71
Maryland	60,440	161,100	$7,367	$13,841	$9,960	$20,992	$1,912	$4,274
Massachusetts	20,580	69,930	$3,301	$7,049	$4,432	$10,453	$851	$2,093
Michigan	7,230	33,870	$724	$2,259	$957	$3,432	$177	$689
Minnesota	4,500	20,910	$405	$1,443	$574	$2,234	$106	$467
Mississippi	2,510	8,620	$149	$401	$201	$666	$36	$131
Missouri	9,620	33,510	$808	$2,102	$1,092	$3,251	$194	$605
Montana	940	3,560	$62	$173	$75	$267	$15	$52
Nebraska	1,480	6,390	$101	$375	$152	$630	$25	$109
Nevada	590	5,980	$54	$335	$76	$572	$13	$118
New Hampshire	2,700	8,750	$259	$631	$352	$970	$68	$196
New Jersey	6,110	30,450	$972	$2,758	$1,272	$4,128	$272	$936
New Mexico	23,920	58,880	$2,641	$4,308	$3,323	$6,403	$623	$1,208
New York	22,150	82,180	$2,369	$7,312	$3,231	$11,612	$720	$2,676
North Carolina	8,660	36,680	$885	$2,424	$1,486	$4,245	$239	$781
North Dakota	550	2,270	$38	$127	$51	$209	$9	$42
Ohio	13,010	50,150	$1,089	$3,156	$1,504	$5,135	$266	$964
Oklahoma	1,990	9,340	$139	$506	$185	$808	$32	$149
Oregon	2,360	12,430	$238	$835	$418	$1,401	$71	$273
Pennsylvania	13,050	53,670	$1,462	$4,132	$1,956	$6,229	$360	$1,245
Rhode Island	2,770	8,300	$220	$533	$306	$843	$63	$181
South Carolina	2,970	13,510	$221	$734	$328	$1,196	$58	$237
South Dakota	440	2,220	$27	$114	$35	$199	$6	$34
Tennessee	11,890	41,760	$987	$2,797	$1,332	$4,205	$231	$792
Texas	13,690	87,540	$1,315	$5,686	$2,054	$9,522	$302	$1,703
Utah	5,140	18,580	$400	$1,079	$578	$1,768	$100	$325
Vermont	440	2,000	$33	$110	$42	$172	$8	$38
Virginia	20,680	62,380	$2,244	$4,803	$2,836	$7,211	$546	$1,447
Washington	8,790	32,150	$1,265	$2,913	$2,137	$5,144	$322	$953
West Virginia	830	3,640	$58	$201	$87	$337	$15	$66
Wisconsin	4,050	18,680	$318	$1,117	$456	$1,812	$81	$356
Wyoming	320	1,390	$21	$70	$26	$124	$5	$26

Source: PwC calculations based on the IMPLAN model.

Note: Details may not add to totals due to rounding.

Table A-5. The Economic Impact of Federal R&D Investment as a Share of State Total, 2018

(Percentage of State Total)

	Federal R&D Supported Total Employment / State Total Employment	Federal R&D Supported Total Labor Income / State Total Labor Income	Federal R&D Supported Total Value Added / State Total GDP
Alabama	2.0%	2.4%	2.3%
Alaska	0.5%	0.5%	0.5%
Arizona	0.7%	0.8%	0.8%
Arkansas	0.3%	0.3%	0.3%
California	0.9%	1.2%	1.1%
Colorado	1.0%	1.2%	1.2%
Connecticut	1.3%	1.5%	1.4%
Delaware	0.5%	0.6%	0.5%
District of Columbia	3.2%	3.4%	3.2%
Florida	0.6%	0.7%	0.7%
Georgia	0.5%	0.6%	0.6%
Hawaii	0.6%	0.6%	0.5%
Idaho	0.9%	1.1%	1.0%
Illinois	0.7%	0.8%	0.8%
Indiana	0.4%	0.4%	0.5%
Iowa	0.7%	0.7%	0.7%
Kansas	0.4%	0.4%	0.4%
Kentucky	0.4%	0.4%	0.4%
Louisiana	0.4%	0.4%	0.4%
Maine	0.5%	0.5%	0.5%
Maryland	4.3%	5.4%	5.1%
Massachusetts	1.4%	1.9%	1.8%
Michigan	0.6%	0.7%	0.7%
Minnesota	0.6%	0.6%	0.6%
Mississippi	0.5%	0.6%	0.6%
Missouri	0.9%	1.0%	1.0%
Montana	0.5%	0.5%	0.5%
Nebraska	0.5%	0.5%	0.5%
Nevada	0.3%	0.3%	0.3%
New Hampshire	1.0%	1.1%	1.1%
New Jersey	0.5%	0.7%	0.7%
New Mexico	5.3%	7.8%	6.4%
New York	0.6%	0.7%	0.7%
North Carolina	0.6%	0.7%	0.8%
North Dakota	0.4%	0.4%	0.4%
Ohio	0.7%	0.8%	0.8%
Oklahoma	0.4%	0.4%	0.4%
Oregon	0.5%	0.6%	0.6%
Pennsylvania	0.7%	0.8%	0.8%
Rhode Island	1.3%	1.4%	1.4%
South Carolina	0.5%	0.5%	0.5%
South Dakota	0.4%	0.4%	0.4%
Tennessee	1.0%	1.2%	1.2%
Texas	0.5%	0.5%	0.5%
Utah	0.9%	1.0%	1.0%
Vermont	0.5%	0.5%	0.5%
Virginia	1.2%	1.4%	1.4%
Washington	0.7%	0.9%	0.9%
West Virginia	0.4%	0.4%	0.4%
Wisconsin	0.5%	0.5%	0.5%
Wyoming	0.3%	0.3%	0.3%

Source: PwC calculations based on the IMPLAN model.

Table A-6. The Economic Impact of Federal R&D Investment in the Defense Sector by State, 2018

(Dollar amounts in millions)

	Employment		Labor Income		Value Added		Tax Impact	
	Direct	Total	Direct	Total	Direct	Total	Direct	Total
US Total	**199,150**	**701,000**	**$22,491**	**$53,841**	**$30,706**	**$83,690**	**$5,688**	**$16,567**
Alabama	16,760	44,900	$1,404	$2,792	$1,863	$4,274	$315	$773
Alaska	260	860	$23	$59	$26	$95	$5	$16
Arizona	4,700	18,770	$448	$1,205	$667	$1,951	$110	$368
Arkansas	220	1,510	$13	$74	$18	$122	$3	$26
California	22,700	91,420	$3,789	$8,769	$5,595	$14,067	$1,013	$2,750
Colorado	2,800	11,170	$292	$799	$398	$1,224	$73	$226
Connecticut	6,560	20,140	$817	$1,806	$1,083	$2,726	$229	$598
Delaware	90	410	$11	$32	$13	$55	$3	$10
District of Columbia	8,510	16,770	$1,161	$2,054	$1,305	$2,595	$277	$535
Florida	8,680	40,980	$756	$2,433	$1,052	$3,883	$180	$778
Georgia	2,110	9,500	$185	$597	$263	$987	$44	$182
Hawaii	800	2,950	$70	$186	$75	$282	$15	$60
Idaho	430	1,480	$41	$90	$53	$135	$10	$26
Illinois	4,820	20,280	$544	$1,598	$770	$2,535	$141	$516
Indiana	980	5,330	$83	$325	$175	$605	$24	$104
Iowa	1,060	3,580	$76	$203	$110	$340	$19	$62
Kansas	200	1,170	$15	$66	$22	$109	$4	$20
Kentucky	190	930	$13	$50	$17	$78	$3	$16
Louisiana	280	1,560	$20	$85	$28	$154	$4	$28
Maine	120	530	$8	$28	$11	$44	$2	$10
Maryland	13,840	37,440	$1,697	$3,214	$2,294	$4,881	$439	$982
Massachusetts	7,700	26,160	$1,235	$2,636	$1,658	$3,910	$319	$783
Michigan	2,750	12,630	$275	$844	$363	$1,281	$67	$261
Minnesota	1,250	5,760	$113	$398	$160	$616	$30	$130
Mississippi	1,530	5,210	$90	$241	$121	$401	$22	$79
Missouri	5,270	18,420	$442	$1,155	$598	$1,787	$106	$331
Montana	140	530	$9	$26	$11	$40	$2	$8
Nebraska	70	290	$5	$17	$7	$29	$1	$5
Nevada	460	4,470	$42	$251	$59	$428	$10	$91
New Hampshire	1,590	5,100	$153	$369	$208	$566	$40	$115
New Jersey	4,140	20,600	$668	$1,877	$874	$2,808	$186	$640
New Mexico	19,700	48,530	$2,175	$3,550	$2,737	$5,277	$513	$995
New York	8,030	29,990	$857	$2,665	$1,169	$4,233	$261	$969
North Carolina	950	4,010	$97	$265	$163	$464	$26	$86
North Dakota	*	20	*	$1	*	$2	*	*
Ohio	8,600	33,070	$717	$2,078	$991	$3,385	$176	$636
Oklahoma	570	2,630	$40	$142	$53	$227	$9	$43
Oregon	240	1,420	$24	$94	$44	$160	$7	$29
Pennsylvania	5,920	24,510	$663	$1,885	$888	$2,843	$163	$565
Rhode Island	1,650	4,970	$131	$319	$182	$505	$37	$108
South Carolina	1,420	6,440	$105	$350	$157	$570	$28	$113
South Dakota	80	410	$5	$21	$6	$36	$1	$6
Tennessee	4,650	16,060	$387	$1,079	$523	$1,621	$90	$309
Texas	4,340	27,590	$417	$1,792	$653	$3,002	$96	$541
Utah	3,460	12,300	$269	$715	$389	$1,171	$68	$219
Vermont	40	180	$3	$10	$4	$15	$1	$3
Virginia	15,170	45,710	$1,644	$3,519	$2,079	$5,283	$400	$1,061
Washington	3,010	10,940	$434	$994	$735	$1,756	$110	$327
West Virginia	20	70	$1	$4	$2	$7	*	$1
Wisconsin	270	1,210	$21	$72	$30	$117	$5	$23
Wyoming	20	90	$1	$5	$2	$8	*	$2

Source: PwC calculations based on the IMPLAN model.

Note: Details may not add to totals due to rounding. An asterisk (*) denotes fewer than 5 jobs or less than $500,000.

Table A-7. The Economic Impact of Federal R&D Investment in the Energy Sector by State, 2018

(Dollar amounts in millions)

	Employment		Labor Income		Value Added		Tax Impact	
	Direct	Total	Direct	Total	Direct	Total	Direct	Total
US Total	**31,460**	**112,080**	**$3,624**	**$8,914**	**$5,014**	**$13,865**	**$932**	**$2,782**
Alabama	120	330	$10	$20	$14	$31	$2	$6
Alaska	30	80	$2	$6	$3	$9	*	$2
Arizona	40	180	$4	$11	$6	$18	$1	$3
Arkansas	10	100	$1	$5	$1	$8	*	$2
California	6,270	23,520	$973	$2,222	$1,424	$3,547	$265	$720
Colorado	1,810	5,670	$184	$417	$250	$630	$45	$141
Connecticut	70	240	$9	$21	$12	$32	$2	$6
Delaware	40	180	$5	$14	$5	$24	$1	$4
District of Columbia	2,840	5,250	$372	$632	$427	$802	$91	$175
Florida	90	420	$8	$25	$11	$40	$2	$8
Georgia	110	590	$10	$36	$14	$61	$2	$10
Hawaii	10	20	$1	$1	$1	$2	*	*
Idaho	1,890	6,550	$181	$400	$234	$600	$44	$117
Illinois	4,050	17,180	$458	$1,353	$649	$2,148	$118	$434
Indiana	90	590	$7	$35	$15	$64	$2	$9
Iowa	490	1,670	$35	$95	$51	$159	$9	$29
Kansas	30	160	$2	$9	$3	$15	$1	$3
Kentucky	80	470	$6	$25	$8	$40	$1	$7
Louisiana	10	70	$1	$4	$1	$6	*	$1
Maine	10	90	$1	$5	$1	$8	*	$1
Maryland	150	400	$18	$34	$25	$52	$5	$11
Massachusetts	260	990	$41	$97	$55	$144	$11	$26
Michigan	280	1,200	$27	$80	$36	$122	$7	$26
Minnesota	70	560	$6	$37	$9	$58	$2	$7
Mississippi	10	20	*	$1	$1	$2	*	*
Missouri	140	540	$12	$33	$16	$52	$3	$9
Montana	20	90	$2	$5	$2	$7	*	$1
Nebraska	50	350	$4	$20	$5	$34	$1	$4
Nevada	10	50	$1	$3	$1	$5	*	$1
New Hampshire	20	70	$2	$5	$2	$7	*	$1
New Jersey	490	2,460	$75	$219	$98	$328	$21	$73
New Mexico	2,130	5,190	$235	$380	$296	$565	$55	$108
New York	1,760	6,670	$187	$591	$255	$940	$57	$212
North Carolina	100	490	$10	$31	$17	$55	$3	$9
North Dakota	40	190	$3	$11	$4	$18	$1	$3
Ohio	190	740	$16	$46	$22	$75	$4	$14
Oklahoma	40	240	$3	$13	$4	$21	$1	$3
Oregon	20	120	$2	$8	$4	$13	$1	$3
Pennsylvania	230	980	$26	$75	$34	$113	$6	$22
Rhode Island	10	20	$1	$2	$1	$2	*	$1
South Carolina	260	1,180	$19	$64	$29	$104	$5	$21
South Dakota	10	60	$1	$3	$1	$6	*	$1
Tennessee	4,380	14,620	$368	$989	$497	$1,482	$85	$291
Texas	120	790	$12	$52	$18	$86	$3	$15
Utah	20	160	$2	$9	$2	$14	*	$1
Vermont	10	60	$1	$3	$1	$5	*	$1
Virginia	150	460	$17	$35	$21	$53	$4	$11
Washington	1,350	5,090	$190	$454	$318	$798	$48	$144
West Virginia	660	2,890	$47	$160	$70	$268	$12	$53
Wisconsin	310	1,690	$25	$100	$36	$163	$6	$28
Wyoming	80	350	$5	$18	$7	$31	$1	$7

Source: PwC calculations based on the IMPLAN model.

Note: Details may not add to totals due to rounding. An asterisk (*) denotes fewer than 5 jobs or less than $500,000.

Table A-8. The Economic Impact of Federal R&D Investment in the Health Sector by State, 2018

(Dollar amounts in millions)

	Employment		Labor Income		Value Added		Tax Impact	
	Direct	Total	Direct	Total	Direct	Total	Direct	Total
US Total	**121,220**	**449,230**	**$14,031**	**$34,935**	**$19,785**	**$55,197**	**$3,652**	**$11,003**
Alabama	1,250	3,360	$104	$209	$138	$319	$23	$57
Alaska	40	120	$3	$8	$4	$13	$1	$2
Arizona	900	3,580	$86	$230	$127	$373	$21	$70
Arkansas	200	1,490	$12	$74	$17	$122	$3	$23
California	11,180	45,960	$1,905	$4,426	$2,821	$7,111	$507	$1,376
Colorado	660	2,620	$68	$187	$93	$287	$17	$53
Connecticut	1,920	5,870	$239	$526	$317	$795	$67	$175
Delaware	160	760	$21	$60	$25	$102	$5	$19
District of Columbia	440	870	$60	$107	$67	$135	$14	$27
Florida	2,570	12,140	$224	$721	$312	$1,150	$53	$230
Georgia	3,260	14,650	$285	$921	$405	$1,522	$67	$281
Hawaii	190	690	$16	$44	$17	$66	$4	$14
Idaho	30	110	$3	$7	$4	$10	$1	$2
Illinois	2,380	11,290	$277	$886	$396	$1,416	$72	$264
Indiana	860	4,630	$73	$283	$154	$527	$21	$92
Iowa	1,300	4,350	$93	$247	$134	$412	$23	$76
Kansas	560	3,140	$41	$176	$61	$291	$11	$56
Kentucky	1,420	6,610	$98	$354	$127	$560	$23	$118
Louisiana	740	4,150	$49	$221	$67	$404	$11	$71
Maine	400	1,830	$29	$98	$38	$154	$7	$34
Maryland	31,670	84,640	$3,864	$7,271	$5,224	$11,030	$1,002	$2,241
Massachusetts	9,260	31,220	$1,488	$3,155	$1,998	$4,678	$383	$943
Michigan	2,800	13,380	$281	$891	$372	$1,355	$69	$268
Minnesota	2,350	10,610	$211	$734	$299	$1,136	$55	$244
Mississippi	180	630	$11	$29	$14	$48	$3	$10
Missouri	3,270	11,230	$275	$706	$371	$1,091	$66	$206
Montana	340	1,280	$22	$62	$27	$96	$5	$19
Nebraska	780	3,270	$53	$192	$80	$323	$13	$57
Nevada	40	480	$4	$26	$5	$45	$1	$8
New Hampshire	580	1,850	$56	$134	$75	$205	$15	$42
New Jersey	570	2,850	$92	$260	$121	$389	$26	$89
New Mexico	650	1,610	$72	$117	$90	$175	$17	$33
New York	9,430	34,630	$1,010	$3,087	$1,378	$4,901	$307	$1,140
North Carolina	5,750	23,850	$588	$1,582	$988	$2,773	$159	$519
North Dakota	100	420	$7	$23	$10	$38	$2	$8
Ohio	2,250	8,660	$188	$544	$259	$886	$46	$167
Oklahoma	330	1,500	$23	$82	$31	$130	$5	$25
Oregon	1,010	6,060	$102	$401	$189	$680	$32	$123
Pennsylvania	5,470	22,080	$613	$1,705	$821	$2,570	$151	$522
Rhode Island	740	2,230	$58	$143	$81	$226	$17	$48
South Carolina	770	3,480	$57	$189	$85	$307	$15	$61
South Dakota	120	600	$7	$31	$10	$54	$2	$10
Tennessee	1,370	5,310	$110	$349	$149	$529	$27	$92
Texas	2,970	18,780	$285	$1,220	$447	$2,044	$66	$370
Utah	990	3,520	$77	$205	$111	$335	$19	$63
Vermont	210	930	$15	$51	$20	$80	$4	$18
Virginia	1,150	3,480	$125	$268	$158	$402	$30	$80
Washington	3,150	11,440	$456	$1,041	$772	$1,840	$116	$344
West Virginia	70	320	$5	$17	$7	$29	$1	$5
Wisconsin	2,320	10,390	$182	$622	$260	$1,009	$46	$203
Wyoming	70	280	$4	$14	$5	$24	$1	$5

Source: PwC calculations based on the IMPLAN model.
Note: Details may not add to totals due to rounding.

Table A-9. The Economic Impact of Federal R&D Investment in Other Sectors by State, 2018

(Dollar amounts in millions)

	Employment		Labor Income		Value Added		Tax Impact	
	Direct	Total	Direct	Total	Direct	Total	Direct	Total
US Total	**93,950**	**366,370**	**$10,786**	**$27,761**	**$15,135**	**$43,905**	**$2,757**	**$8,525**
Alabama	1,580	4,260	$132	$264	$175	$404	$30	$73
Alaska	460	1,400	$41	$98	$47	$156	$8	$28
Arizona	1,280	5,490	$122	$349	$181	$566	$30	$100
Arkansas	340	2,310	$20	$114	$28	$188	$5	$39
California	14,960	60,880	$2,523	$5,852	$3,732	$9,394	$673	$1,827
Colorado	5,210	19,630	$539	$1,412	$734	$2,157	$134	$417
Connecticut	980	3,240	$122	$287	$162	$435	$34	$90
Delaware	300	1,440	$38	$111	$46	$192	$9	$35
District of Columbia	3,570	6,660	$470	$805	$538	$1,021	$115	$221
Florida	3,820	18,640	$335	$1,101	$465	$1,758	$79	$343
Georgia	1,770	8,670	$155	$540	$220	$894	$37	$153
Hawaii	460	1,610	$41	$103	$45	$156	$9	$35
Idaho	200	690	$19	$42	$25	$63	$5	$12
Illinois	1,510	7,030	$175	$552	$250	$881	$45	$167
Indiana	880	5,070	$74	$308	$156	$569	$21	$93
Iowa	1,230	4,200	$89	$239	$128	$399	$22	$72
Kansas	490	2,720	$36	$153	$53	$252	$9	$49
Kentucky	490	2,510	$34	$133	$44	$212	$8	$41
Louisiana	720	4,000	$48	$214	$65	$390	$11	$69
Maine	320	1,510	$23	$80	$30	$127	$6	$26
Maryland	14,780	38,630	$1,788	$3,322	$2,417	$5,030	$465	$1,041
Massachusetts	3,360	11,570	$537	$1,160	$721	$1,721	$139	$341
Michigan	1,400	6,660	$141	$444	$186	$674	$34	$134
Minnesota	830	3,980	$74	$274	$106	$425	$20	$86
Mississippi	790	2,760	$49	$130	$65	$215	$11	$42
Missouri	940	3,320	$79	$208	$107	$322	$19	$59
Montana	430	1,650	$28	$81	$35	$124	$7	$24
Nebraska	580	2,480	$39	$146	$59	$244	$10	$42
Nevada	80	980	$8	$54	$11	$93	$2	$17
New Hampshire	510	1,730	$49	$124	$66	$191	$13	$37
New Jersey	900	4,540	$137	$403	$180	$604	$39	$135
New Mexico	1,440	3,550	$159	$260	$200	$386	$37	$73
New York	2,940	10,890	$314	$969	$429	$1,538	$96	$355
North Carolina	1,860	8,350	$190	$546	$318	$954	$51	$167
North Dakota	400	1,650	$28	$92	$37	$151	$7	$30
Ohio	1,960	7,680	$168	$487	$231	$788	$41	$147
Oklahoma	1,040	4,970	$73	$269	$97	$430	$17	$78
Oregon	1,100	4,840	$109	$332	$181	$548	$31	$119
Pennsylvania	1,430	6,090	$160	$466	$214	$703	$39	$136
Rhode Island	370	1,080	$30	$70	$42	$110	$8	$24
South Carolina	520	2,420	$39	$132	$58	$214	$10	$42
South Dakota	230	1,150	$14	$59	$18	$103	$3	$18
Tennessee	1,500	5,760	$121	$380	$164	$574	$29	$101
Texas	6,250	40,390	$601	$2,622	$936	$4,389	$138	$777
Utah	680	2,610	$53	$150	$76	$247	$13	$43
Vermont	180	840	$13	$46	$17	$72	$3	$15
Virginia	4,210	12,730	$458	$981	$578	$1,472	$111	$295
Washington	1,280	4,680	$184	$424	$311	$749	$47	$139
West Virginia	80	360	$5	$20	$8	$33	$1	$6
Wisconsin	1,160	5,390	$91	$322	$130	$523	$23	$102
Wyoming	150	680	$10	$34	$13	$60	$3	$13

Source: PwC calculations based on the IMPLAN model.
Note: Details may not add to totals due to rounding.

Appendix B: Data Sources and Methodology

This Appendix describes the data sources and methodology used to derive the results for the study relating to federal R&D investment and the associated direct, indirect, and induced employment, labor income, value added, and tax impacts.

Estimating Federal R&D Investment in 2018

PwC's estimates of federal R&D investment, consisting of federally funded expenditures for R&D operations, facilities and equipment, primarily rely on data provided by the National Science Foundation (NSF). We exclude from our national estimates R&D performed in the territories. Specifically, from NSF's estimate of federally funded R&D operational expenditures in calendar year 2018, amounting to $127.246 billion, we exclude the share (0.1 percent) that is performed in the territories, resulting in $127.132 billion.[93] We estimate that the associated federally funded R&D capital expenditures in calendar year 2018 amount to $4.174 billion, using NSF data for fiscal year (FY) 2018 indicating that federal outlays for facilities and equipment were 3.3 percent of federal outlays for R&D operations.[94]

We then allocate federal R&D investment by sector using NSF data on federal R&D outlays by agency in FY 2018.[95] In particular, health sector R&D is determined using the share of federal R&D outlays reported by the Department of Health and Human Services. Defense sector R&D is based on the share of federal R&D outlays reported by the Department of Defense, while energy sector R&D is based on the share of federal R&D outlays reported by the Department of Energy (DOE), with DOE Office of Science spending by program allocated between the defense and energy sectors as follows.[96] We assume the following three DOE Office of Science programs are entirely energy related: Basic Energy Sciences, Biological and Environmental Research, and Fusion Energy Sciences. We assume the following three DOE Office of Science programs are 94 percent defense related and 6 percent energy related: Advanced Scientific Computing Research, High Energy Physics, and Nuclear Physics.[97] Thus, in total for these six major programs, 60 percent of R&D spending is deemed energy related and 40 percent defense related. We assume the remainder of the DOE Office of Science R&D budget is split in the same proportion, i.e., 60 percent energy and 40 percent defense.

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[93] National Science Foundation, *National Patterns of R&D Resources: 2017-18 Data Update,* NSF 20-307, Tables 6 and 10, January 8, 2020, available at https://www.nsf.gov/statistics/natlpatterns/. NSF notes that "the data for 2018 are estimates and will later be revised."

[94] National Science Foundation, *Survey of Federal Funds for Research and Development: Fiscal Years 2018-19,* Table 2, January 2020, available at https://ncsesdata.nsf.gov/fedfunds/2018/. Following guidance from the Office of Management and Budget (OMB), each federal agency identifies operational expenditures for the conduct of R&D as well as capital expenditures for "R&D plant", defined as construction and rehabilitation of R&D facilities and acquisition, design, or production of major movable equipment for use in R&D activities. Office of Management and Budget, "Circular No. A-11: Preparation, Submission, and Execution of the Budget", Section 84, December 2019, available at https://www.whitehouse.gov/wp-content/uploads/2018/06/a11.pdf.

[95] National Science Foundation, *Survey of Federal Funds for Research and Development: Fiscal Years 2018-19,* Tables 4 and 53, January 2020, available at https://ncsesdata.nsf.gov/fedfunds/2018/.

[96] Department of Energy, *FY 2020 Congressional Budget Request: Budget in Brief*, page 42, March 2019, available at https://www.energy.gov/sites/prod/files/2019/03/f60/doe-fy2020-budget-in-brief_0.pdf.

[97] NSF data on federal budget authority for R&D by budget function in FY 2018 indicates that the defense budget function is 94 percent of the sum of the defense and energy budget functions. National Science Foundation, *Federal R&D Funding, by Budget Function: Fiscal Years 2018-20,* NSF 20-305, Table 1, December 4, 2019, available at https://ncses.nsf.gov/pubs/nsf20305/#&.

Total federally funded R&D operational expenditures are allocated to the states using NSF data on federally funded R&D operational expenditures by state in calendar year 2017, the most recent data year.[98] Total federally funded R&D expenditures for facilities & equipment are allocated to the states using NSF data on federal obligations for R&D facilities & equipment by state in FY 2018 (data on expenditures by state is not available).[99] It should be noted that federal obligations do not necessarily correspond to federal outlays, and as such our state-level estimates based on federal obligations data are subject to additional uncertainty. Federally funded R&D expenditures by sector are allocated to the states using NSF data on federal obligations for R&D by agency by state in FY 2018, DOE budget state tables for FY 2018, and DOE information on ARPA-E awards by state in calendar year 2018.[100] A raking procedure is applied to the state level data by sector to ensure consistency with national and state totals.[101]

Estimating the Direct, Indirect, and Induced Economic Impacts

We have relied on the IMPLAN national and state models for 2018 to calculate the economic impacts of federal R&D investment. IMPLAN is a modeling system developed for estimating economic impacts and is similar to the Regional Input-Output Modeling System developed by the US Department of Commerce. The model is primarily based on government data sources.

IMPLAN is built around an “input-output” table that relates the purchases that each industry has made from other industries to the value of the output of each industry. To meet the demand for goods and services from an industry, purchases are made in other industries according to the patterns recorded in the input-output table. These purchases in turn spark still more purchases by the industry’s suppliers, and so on. Additionally, employees and business owners make personal purchases out of the additional income that is generated by this process, further increasing demand that ripples through the economy. Multipliers describe these iterations. The Type I multiplier measures the direct and indirect effects of a change in economic activity. It captures the inter-industry effects only, i.e., industries buying from local industries. The SAM (Social Accounting Matrix) multiplier captures the direct and indirect effects. In addition, it also reflects induced effects (i.e., changes in spending from households as income increases or decreases due to the changes in production).

Economic multipliers are often used to measure the overall change in production that would result from a marginal increase in a particular industry. For example, a value added multiplier converts a $1 million increase in output of an industry into the total change in value added throughout the supply chain. For this study, PwC has treated the Scientific Research and Development Services sector in the North American Industrial Classification System (NAICS) as the originating industry, while recognizing the fact that a large number of researchers are also

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[98] National Science Foundation, *National Patterns of R&D Resources: 2017-18 Data Update,* NSF 20-307, 10, January 8, 2020, available at https://www.nsf.gov/statistics/natlpatterns/

[99] National Science Foundation, *Survey of Federal Funds for Research and Development: Fiscal Years 2018-19,* Table 93, January 2020, available at https://ncsesdata.nsf.gov/fedfunds/2018/.

[100] National Science Foundation, *Survey of Federal Funds for Research and Development: Fiscal Years 2018-19,* Tables 91 and 93, January 2020, available at https://ncsesdata.nsf.gov/fedfunds/2018/; Department of Energy, *FY 2020 Congressional Budget Request: State Tables Preliminary*, March 2019, available at https://www.energy.gov/sites/prod/files/2019/03/f60/doe-fy2020-state-table.pdf; ARPA-E Projects, available at https://arpa-e.energy.gov/?q=project-listing.

[101] The raking process uses as control totals the national totals for each sector and the state totals, and adjusts data at the state level for each sector to be consistent with the control totals. For more on raking, see H.L. Oh and F. Scheuren, “Modified Raking Ratio Estimation,” *Survey Methodology*, Vol. 13(2), pp. 209-219, 1987.

employed directly by the federal government.[102] Through the IMPLAN multipliers for the NAICS R&D sector, PwC has quantified the direct, indirect, and induced impacts of federal R&D investment in terms of employment, labor income, value added, and tax payments at the national and state level. To estimate the national level direct effect, PwC first estimated the direct impact of such spending at the state level and then treated the sum totals across all states and the District of Columbia as the national direct impact. The national-level indirect and induced impacts are estimated based on such national direct impact.

Because IMPLAN regional models capture only the indirect and induced effects within a region, the indirect and induced effects crossing state borders (“cross-state spillover effects”) are not captured by the IMPLAN state models. PwC quantified the cross-state spillover effects and allocated them proportionally to each state. The state indirect and induced effects reported throughout this study include such allocation of the cross-state spillover effects.

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[102] The Scientific Research and Development Services sector comprises establishments primarily engaged in conducting original investigation to gain new knowledge (research) and creating new or improved products or processes based on research findings or other scientific knowledge (experimental development). Because the activity of research is similar whether it is performed in this sector or by researchers in the federal government, the indirect and induced economic effects are expected to be similar per dollar of direct expenditure.