American Energy Innovation Council

ENERGY INNOVATION: FUELING AMERICA'S ECONOMIC ENGINE

November 2018

BIPARTISAN POLICY CENTER

THE AMERICAN ENERGY INNOVATION COUNCIL

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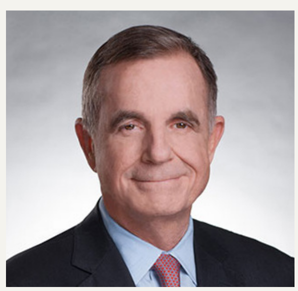

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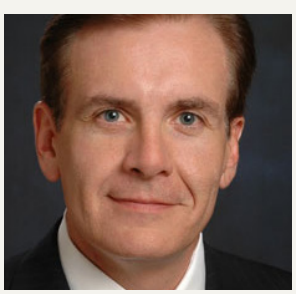

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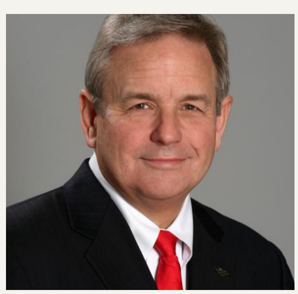

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*Ursula Burns, CEO of Xerox; Jeff Immelt, chairman and CEO of G.E.; and Tom Linebarger, chairman and CEO of Cummins Inc. were founding members and serve in emeritus status. Anthony F. Earley Jr., former executive chair of the board at the PG&E Corporation, retired as of December 2017.

THE AMERICAN ENERGY INNOVATION COUNCIL

American Energy Innovation Council

WHO WE ARE

The American Energy Innovation Council, originally formed in 2010, is a group of eleven corporate leaders who share a common concern over America's insufficient commitment to energy innovation. We speak as executives with broad-based success in innovation, who, in the course of our careers, have been called upon to overcome obstacles, seize opportunities, and make difficult decisions, all in the pursuit of building great American companies.

OUR MISSION

The mission of the American Energy Innovation Council is to foster strong economic growth, create jobs in new industries, and reestablish America's energy technology leadership through robust public and private investments in the development of world-changing energy technologies.

The American Energy Innovation Council is a project of the Bipartisan Policy Center.

BIPARTISAN POLICY CENTER

ABOUT THE BIPARTISAN POLICY CENTER

The Bipartisan Policy Center is a non-profit organization that combines the best ideas from both parties to promote health, security, and opportunity for all Americans. BPC drives principled and politically viable policy solutions through the power of rigorous analysis, painstaking negotiation, and aggressive advocacy.

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LETTER FROM THE PRINCIPALS

We formed the American Energy Innovation Council around a shared understanding that robust federal investments in energy innovation are crucial to America's national security, international competitiveness, and long-term economic stability. In the eight years since the council was founded, the political, economic, and energy landscape has changed significantly at home and around the world. New and enhanced technologies and processes—such as large-scale energy storage, blockchain, advanced nuclear reactors, demand response, and others—have emerged and are transforming how the nation produces and consumes energy while upending traditional business models in the energy sector and beyond. These developments present exciting opportunities and will underlay future advances in energy technology, but they also present very real challenges and risks that will be important for industry leaders and decision makers to address.

Tackling the complex problems at the nexus of science, technology, and policy associated with these developments will be difficult enough. Adding to the challenge is the reality that foreign countries are rapidly increasing their investments in science and technology as the race for global technology leadership picks up speed, while U.S. research and development (R&D) investments remain sluggish by comparison. The risk of falling behind other nations in science and technology presents very real economic and national security threats by undermining America's ability to lead, let alone compete, in the global technology markets of tomorrow. Nowhere is this more concerning than in energy technology, which helps fuel the U.S. economy.

At times, the scale of the challenge may seem daunting. Despite these threats, the United States is a nation of innovators and entrepreneurs who have a proven track record of rising to the occasion when the need presents itself. U.S. industries, universities, and national labs are the envy of the world, and researchers from these institutions have effectively partnered together throughout the nation's history to overcome obstacles and to assert America's technology dominance, especially in the energy sector. With a renewed commitment to energy innovation, the United States can continue to lead the world in solving some of the most pressing global problems and to spearhead the next generation of advanced energy technologies.

As business leaders with decades of combined experience in the energy sector, we have firsthand knowledge of the need for balanced investments from both the public and private sectors to develop energy breakthroughs. **Federal funding fills crucial gaps where the private sector cannot or will not invest and has been pivotal in facilitating some of the greatest advances in energy technology over the past century.** It is crucial to restore strong funding levels for energy R&D to ensure the United States can continue to do so in the future. We look forward to continuing to work with lawmakers to encourage their renewed support for energy innovation as an investment in America's long-term economic growth and prosperity.

INTRODUCTION

Technological innovation can improve productivity across industries and create entirely new ones. This is one among many reasons why economists agree that innovation is a driver of long-term economic growth[1] and stability—and why at least 50 percent[2] of U.S. annual GDP growth can be traced to increases in innovation. Advances in energy technology deserve particular attention since energy underlies virtually every facet of modern life, and without a sufficient, reliable, and affordable source of energy, the U.S. economy would grind to a halt. The significance of energy to the economy and national security is why the United States has spent decades investing significant amounts of time, money, and resources into developing advanced energy technology, propelling the nation to a position of global leadership in many sectors. Ongoing research and development (R&D) will be crucial to enabling the United States to continue developing game-changing energy technologies, seize billion-dollar economic opportunities in the global energy markets of tomorrow, and maintain America's global leadership and competitiveness.

Recognizing the importance of energy innovation to long-term economic growth and competitiveness, a group of business leaders formed the American Energy Innovation Council (AEIC) in 2010 to support strong federal investments in energy R&D. Drawing on the collective experience gained from leading successful businesses engaged in R&D, the AEIC principals have long recognized the necessary and complementary roles of the public and private sectors across the innovation cycle as well as the role of federal investments in key areas that strengthen the entire system. The council has published numerous reports, white papers, and case studies exploring this topic and are in firm agreement that staunch, targeted federal investments in energy R&D are crucial to bolstering America's long-term economic health and competitiveness. In support of this mission, the council supports the following set of recommendations to maintain and strengthen U.S. energy technology leadership.

RECOMMENDATIONS

1. Build on efforts to develop comprehensive assessments and a strategic direction for the nation's energy sector.

2. Invest $16 billion per year in advanced energy innovation.

3. Fund ARPA-E at $1 billion per year. At a minimum, ARPA-E should receive $400 million per year in fiscal year (FY) 2020, a $34 million increase over FY 2019, which would allow one additional high-impact R&D program to be released by ARPA-E in that year.

4. Support and expand new and innovative institutional arrangements, such as energy innovation hubs, energy frontier research centers, the Manufacturing USA program, and the Energy Materials Network.

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5. Make the Department of Energy (DOE) work smarter—along the ARPA-E model where appropriate.
6. Establish a New Energy Challenge Program for high-impact pilot projects.
7. Establish regionally centered innovation programs.
8. Have the federal government support creative efforts to incentivize private-sector investment in energy R&D.

Building on the core recommendations AEIC has touted for years, this report lays out the current state of U.S. and global R&D investments and outlines both the challenges and impact of making robust federal investments in energy R&D to America's long-term prosperity and well-being. This report also includes new data from a recently launched survey of recipients of federally funded energy R&D that explores the impact of institutional practices and features at DOE on R&D outcomes.

"The United States must work to maintain a leadership position in the global market for cleaner, lower-cost energy technologies. A strong, focused, and well-funded Department of Energy effort in clean energy technologies is critical—from basic research to pilot demonstration."

– Jay Faison

OVERVIEW

A source of much of the energy abundance Americans enjoy today can be traced to federal R&D carried out in the nation's renowned universities, national laboratories, and industry in decades past. America's unparalleled R&D infrastructure has supported, and continues to support, game-changing innovations that not only push the economy forward, but produce discoveries and inventions that improve the quality of life of every American. These breakthroughs have had far-reaching impacts both inside and outside of the energy sector.

Building on basic and applied atomic research conducted during the Manhattan Project, the U.S. government began developing peaceful applications of nuclear technology following the end of World War II. The federal government built the first nuclear reactor[3] in the 1950s before transferring the commercial development of the technology to the private sector—and in doing so laid the bedrock for the modern nuclear energy industry, which contributed $60 billion[4] to U.S. GDP in 2015 and today supplies one-fifth[5] of U.S. electricity and nearly three-fifths[6] of U.S. carbon-free electricity. Federal atomic energy R&D likewise spawned advances in nuclear medicine, including the development of Technetium-99m, the most widely used[7] tracer in nuclear diagnostic procedures; it enables doctors to detect and treat diseases, saving millions of lives.

Today's shale boom can trace its history to late-stage research and demonstration initiatives done by industry but funded by DOE, such as seismic mapping, horizontal drilling, and advanced drill-bit technology developed during the 1970s.

Modern solar cells and wind turbines can also trace their roots to R&D carried out at the National Renewable Energy Laboratory, founded as the Solar Energy Research Institute in 1974. Building on early efforts to improve efficiency and lower costs, wind and solar energy production has quadrupled[8] over the past decade while costs for these technologies have been cut nearly in half.

There is no shortage of evidence of America's long, rich history of leveraging public and private resources to spearhead the development of transformative energy technologies and the economic, environmental, and energy security benefits American consumers and businesses have enjoyed because of U.S. technology leadership. Unfortunately, in recent years U.S. investments in energy innovation have not kept up with the clear need, which risks undermining long-term U.S. economic growth, national security, and global competitiveness.

> **"Foreign competitors are rapidly increasing their investments in science and technology as the race for global technology leadership picks up speed. Restoring strong federal investments in energy innovation is a matter of critical economic and national security concern and is necessary to ensure America's long-term growth, competitiveness, and prosperity."**
>
> *–Norman Augustine*

OVERVIEW

Maintaining U.S. leadership in energy technology innovation and continuing to capture the benefits that come along with it require understanding how the innovation process works in practice. New technologies must typically overcome two "valleys of death" on the iterative path from idea to product. The first is the *technological valley of death*, which refers to promising new ideas before they've demonstrated technical proof of concept. The second is the *commercial valley of death*, which refers to feasible technologies that have uncertain economic viability or commercial applications. The energy sector faces a series of unique challenges compared with other industries that make it especially difficult for even the most promising projects to attract private-sector investment that could help them surpass these critical stages:

1. **Capital-Intensive:** Many energy R&D projects—such as developing grid-scale energy storage systems, creating new nuclear energy technologies, or pilot-testing horizontal drilling technology—are expensive and require access to sophisticated equipment, facilities, and expertise without a guarantee of an adequate return on investment. This is an expense that few, if any, companies can undertake alone.

2. **Long Payback Periods:** New energy technologies often take years, if not decades, to mature. This payback schedule is ill-suited to private industry, which typically assesses growth on quarterly earnings reports[9] and expects much quicker returns than energy R&D projects can deliver. Unfortunately, this makes it nearly impossible for industry to invest in basic and applied research and even some longer-range development activities.

3. **Valued as a Commodity:** Product differentiation does not drive energy innovation in the same way as in other industries. Compared with vehicles or cell phones, where companies innovate to distinguish their products and compete in the market, most end-users value energy availability rather than where it comes from. This reduces the incentive to develop innovative energy technologies.

4. **Regulatory Uncertainty and Fragmentation:** The energy market is fragmented and subject to regulatory uncertainty, and investors are wary of policy risks that might impede their ability to secure an adequate return on investment.

For the reasons listed above, the private sector generally underinvests in energy R&D. The risks associated with energy R&D are frequently too high for the private sector to make the investments needed on its own to match the scale of the opportunity of developing transformational energy technologies. Decades of federal energy R&D funding has filled crucial investment gaps and propelled the nation to its current state of energy abundance and global technological leadership. Robust public investments in energy R&D are critical to ensuring that U.S. industries and businesses continue to maintain a leadership position in the energy technology markets of tomorrow. However, recent trends in U.S. R&D spending across the board suggest the United States is at risk of ceding its technology leadership within the next decade, which risks undermining the ability of U.S. businesses to compete globally as nations around the world step up their commitments to energy R&D.

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Recognizing the economic opportunities and international leverage gained from leading emerging advanced technology markets, countries around the world are expanding their investments in science and technology as competition for technology leadership, and by extension global leadership, accelerates.

GLOBAL R&D INVESTMENT TRENDS

Global R&D investment more than doubled between 2000 and 2015, rising to a total of $2 trillion[10] in 2018, with Asia achieving the highest rate of growth. During this time, the U.S. share of global R&D fell from 37 percent to 26 percent.[11] On its own, this trend is not concerning—as more countries expand their R&D programs the U.S. share of global R&D will naturally shrink. However, many indicators suggest that U.S. R&D investment growth remains sluggish compared with other nations. Without an increased and sustained commitment to science and technology, the United States is fast approaching an inflection point after which the country risks losing its global position of technology leadership.

Two of the most telling indicators of a nation's innovative capacity are total R&D spending and R&D intensity, which refers to the ratio of a country's total R&D spending relative to the size of its economy. The United States is at risk of falling behind in both. While America remains the top global performer of R&D with regards to total dollars spent, China is expected to surpass the United States by 2026,[12] if not sooner. Meanwhile, America's R&D intensity has hovered around 2.7 percent[13] over the past decade. The United States dropped from 8th to 11th place[14] in global R&D intensity between 2009 and 2015 as other nations stepped up their R&D programs (Figure 1). South Korea and Japan now invest a greater share into R&D relative to the size of their economies, with R&D intensities of 4.3 percent[15] and 3.5 percent[16] respectively in 2016.

> **"We are at a moment of high risk and great promise. We need good policies to support adoption of existing technologies that can reduce the impacts of climate. At the same time, we need to ensure that governments are supporting innovation and helping deliver the resulting breakthroughs to the people and places that need them most."**
>
> *—Bill Gates*

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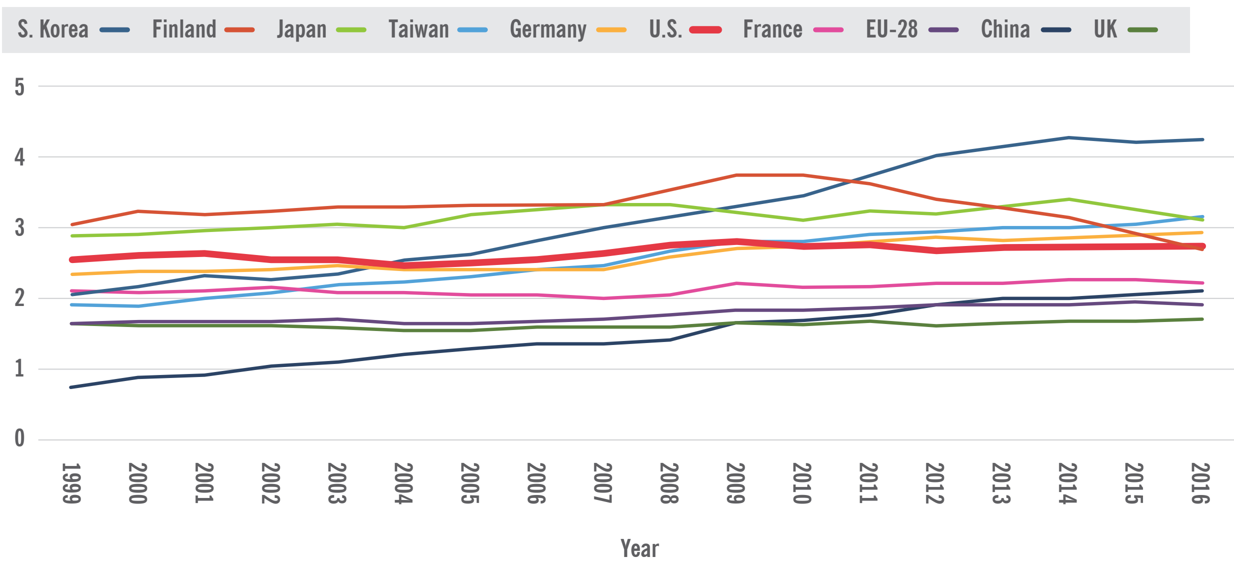
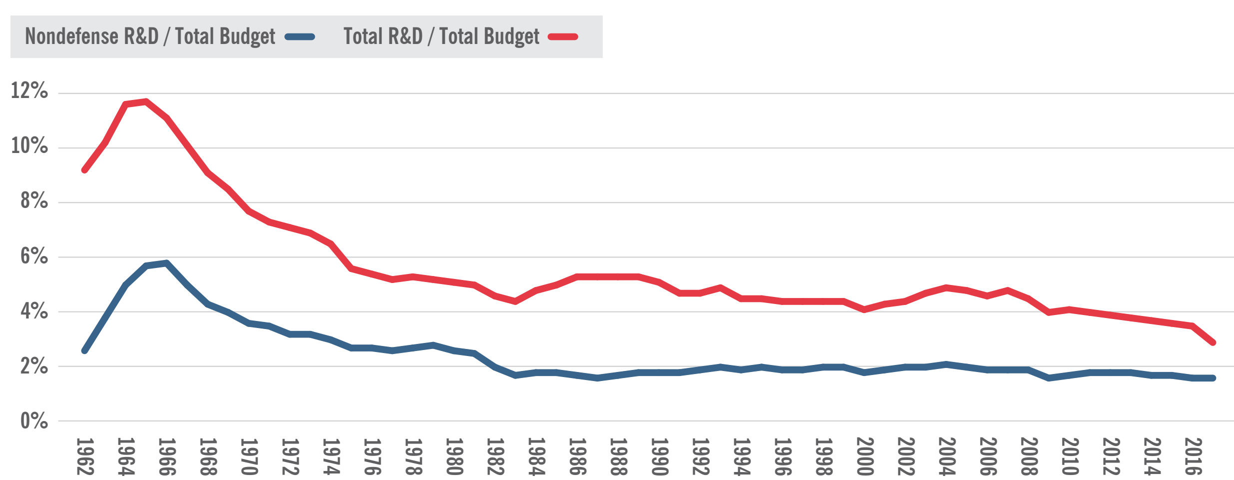
FIGURE 1. NATIONAL R&D INTENSITY: GROSS R&D INVESTMENT AS A PERCENT OF GDP



Source: American Association for the Advancement of Science, "Historical Trends in Federal R&D." March 2018.
Available at: https://www.aaas.org/page/historical-trends-federal-rd [17]

FIGURE 2. U.S. R&D BUDGET AS A PERCENT OF THE FEDERAL BUDGET, FY 1962-2017 IN OUTLAYS



Source: American Association for the Advancement of Science, "Historical Trends in Federal R&D." 2018.
Available at: https://www.aaas.org/page/historical-trends-federal-rd [18]

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Other indicators of innovative capacity include the number of new products, patents, peer-reviewed publications, or follow-on funding stimulated by R&D programs. A nation's academic infrastructure, university rankings, and scientific workforce are also telling indicators. While the United States maintains leadership in overall innovation quality in many of these categories—it still attracts the most[19] venture capital and is the largest producer in high-technology manufacturing sectors—it is the rapid pace at which other nations are strengthening their commitment to R&D, while the United States remains relatively dormant, that poses a threat to U.S. leadership. China, for example, published nearly five times[20] more scientific publications in 2016 than it did in 2003, is actively expanding its academic and state-owned R&D infrastructure, and graduates more[21] new engineers annually than currently reside in the United States. Consider that in 2013 China attracted $3 billion in venture capital investment and just three years later had attracted 11 times[22] as much—a remarkable rate of growth.

Congress took notice of these rising threats over a decade ago when it asked the National Academy of Science to examine the state of U.S. leadership in science and technology. The National Academy published its *Rising Above the Gathering Storm* [23] report in 2007, concluding that the United States was at risk of falling behind other nations without increased R&D investments. As a response, Congress passed the America COMPETES Act, which set a doubling path[24] for R&D budgets at key federal science agencies, including DOE. In 2017, Congress reasserted the importance of maintaining U.S. commitments to science and technology by passing a successor to COMPETES as part of the American Innovation and Competitiveness Act.[25] While this was a positive step that included some productive programmatic changes, the American Innovation and Competitiveness Act did not authorize or recommend funding levels for key science programs. Today, the United States remains far short of the goal of doubling R&D funding by 2021 as set in the 2010 reauthorization of America COMPETES, and the nation is beginning to witness the repercussions.

> **"Federal funding fills crucial gaps where the private sector does not invest and has been pivotal in facilitating some of the greatest advances in energy technology in recent years. But it is crucial to restore strong funding levels for energy R&D to ensure we can continue to innovate our energy future."**
>
> *—Chad Holliday*

America's rank and reputation in international innovation indices has begun to fall. In 2018, the United States dropped out[26] of the Bloomberg Innovation Index's top 10 for the first time. In a separate index report, the United States came in as low as 12th[27] in an index of impact on the overall global innovation ecosystem in 2015. In addition,

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the U.S. Chamber of Commerce's I.P. index,[28] which ranks international intellectual property standards and their impact on innovation, shows a shrinking gap between America's lead over other economies in Europe and Asia; it found that for certain metrics other nations now outperform the United States.

Maintaining global technology leadership carries far-reaching economic and soft-power benefits. Beyond the productivity gains and economic benefits of developing and exporting advanced technology, the world's technology leaders attract greater investment, entrepreneurs, and scientific talent compared with nations that invest less in R&D. Drawing and concentrating technical expertise and R&D infrastructure in one place facilitates a self-sustaining innovation hub that stimulates further R&D activities and the development of supply chains—and associated businesses and jobs—necessary to produce new innovations. This enables the host nations to capture market share in major technology markets and the economic and political clout that comes along with it. As new technologies grow and take hold, these are enormous opportunities the United States stands to lose without a renewed federal commitment to R&D investment.

The United States remains a global technology powerhouse because the nation is still reaping the benefits of past investments. America's world-renowned system of national labs, universities, and industries have spearheaded decades of R&D, underpinning many of the technologies now ubiquitous in major global industries. However, other nations have learned from the U.S. example and are investing in R&D at a pace the United States hasn't embraced in decades. As other nations ramp-up their commitment to R&D investment, decision makers will be forced to ask themselves whether the United States will be merely a participant in, or leader of, the technology markets of tomorrow and make the needed investments accordingly.

THE INNOVATION CYCLE

R&D is often classified into one of three categories: basic research, applied research, or development.[29] Basic research seeks to generate new knowledge or gain better understanding of phenomena without an application in mind, while applied research seeks to gain knowledge to determine how to meet a specific need. The development stage is focused on applying knowledge to produce useful products or processes. The conventional view of the innovation process depicts a linear path that flows from basic research, to applied research and then to development and eventual commercialization. This intellectual construct has drawbacks and reinforces the false idea that innovation is segregated, one-directional, and flows from one stage to the next when it is in fact interconnected, iterative, and has bilateral flows. Despite these limitations, this system remains useful to distinguish differences between expected outputs, time horizons, and risk profiles. It's also useful in assessing the overall health of the U.S. innovation ecosystem.

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It is generally accepted that early-stage basic research, despite being high risk, is incredibly valuable and may have unanticipated commercial applications or public benefits. The accidental discovery of penicillin,[30] which revolutionized the field of medicine and has saved countless lives, is a classic example. However, the process flows both ways. The development of a new technology prototype may reveal a problem that requires further fundamental discoveries to solve or spark new discovery. For instance, the steam engine[31] was invented before the laws of thermodynamics were proposed, but this invention was monumental in improving an understanding of the underlying physics of thermal processes.

As scientists' understanding of the innovation process evolves, they are beginning to realize that the divide among basic, applied, and developmental research embedded in the conventional linear pipeline model is not only blurred and artificial, but harmful to scientific advancement. It has led to the increasing segregation of basic and applied research between government and industry in the United States, which has tipped the innovation system out of balance by inhibiting the two-way flow and cross-pollination of ideas and resources so critical to the development of advanced technologies, all the way from discovery to demonstration and deployment. Yet government and industry have demonstrated time and again that each can play crucial and complementary roles across the innovation cycle.

COMPOSITION OF U.S. AND GLOBAL R&D

Although overall U.S. R&D funding has risen—driven mainly by the private sector—in 2015, the federal share of R&D funding in the United States reached its lowest point[32] since record keeping began in 1953 (Figure 3). While private R&D investment increased over the same period, it hasn't offset the decline in federal spending in key areas. Closer examination reveals a shift in the composition of R&D being carried out by the public and private sectors, as well as an investment gap in important areas of R&D. These trends indicate that the United States is undermining its ability to develop game-changing innovations as it did in decades past.

> **"Technological innovations are a critical part of our energy future. We must support them through public and private funding. Overall U.S. R&D funding has risen, driven mainly by the private sector. The share of government research funding is at the lowest ever. It's imperative that we work together to fix this problem."**
>
> *—John Doerr*

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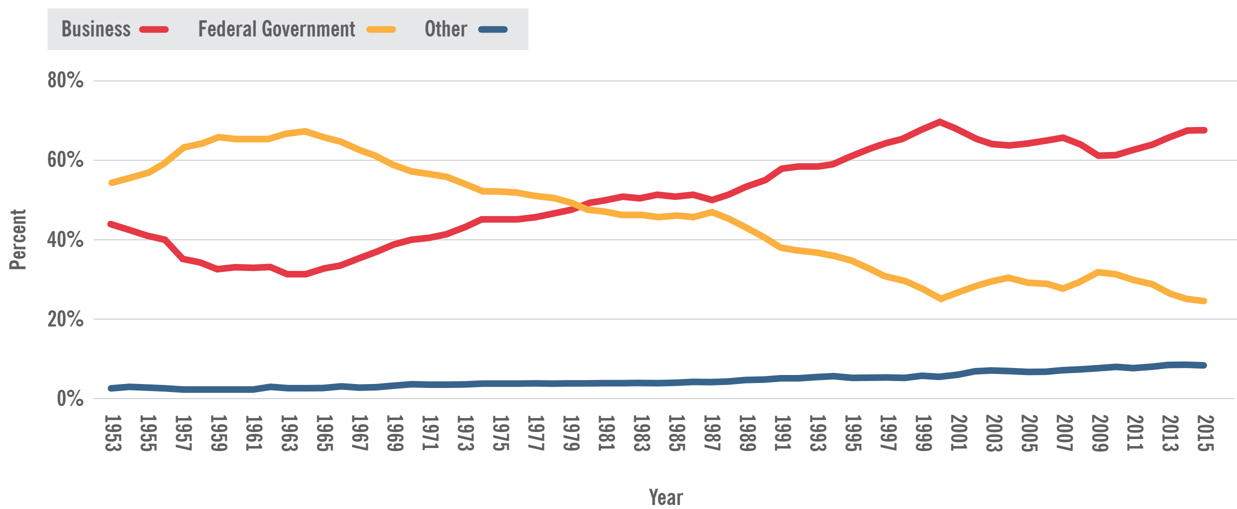
FIGURE 3. U.S. TOTAL R&D EXPENDITURES BY SOURCE OF FUNDS, 1953-2015



Source: National Science Board. 2018. Science and Engineering Indicators 2018. NSB-2018-1. Alexandria, VA: National Science Foundation. Available at: https://www.nsf.gov/statistics/indicators/ [33]

Government has long supplied the majority of funding for basic research in the United States because basic research is often at a stage too early to have identified a commercial application and because it typically carries higher risks than the private sector is willing or able to tolerate. The U.S. government historically played a larger role in applied R&D as well but, as Figures 4, 5, and 6 illustrate, private actors increasingly[34] carry out late-stage research while basic research is left to the government. While certain private institutions and high-net-worth angel investors invest in basic research, they are increasingly the exception to the rule. Today, many companies with large R&D budgets tend to invest in incremental improvements to existing technology to more quickly bring new products to market. The decline of Bell Labs is one of many examples suggesting that the private sector is increasingly[35] focused on short-term[36] returns and as a result has shifted resources to later stages of research that have quicker payoffs. Unfortunately, these patterns have magnified the challenges of declining public R&D investments and resulted in a dwindling pool of funding for research dedicated to producing new discoveries and making fundamental advances in technology that can transform entire industries and economies.

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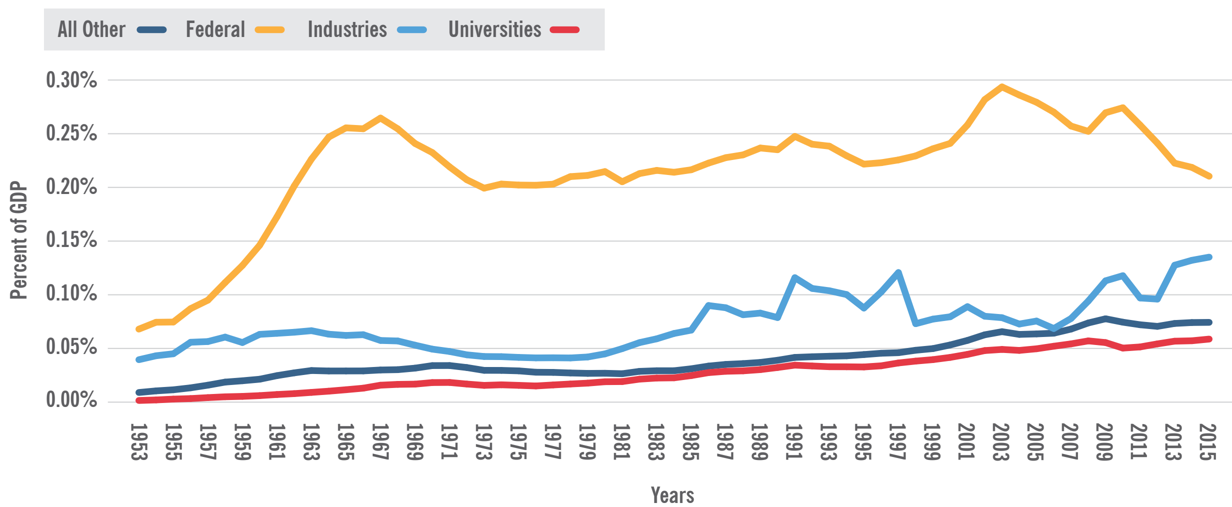
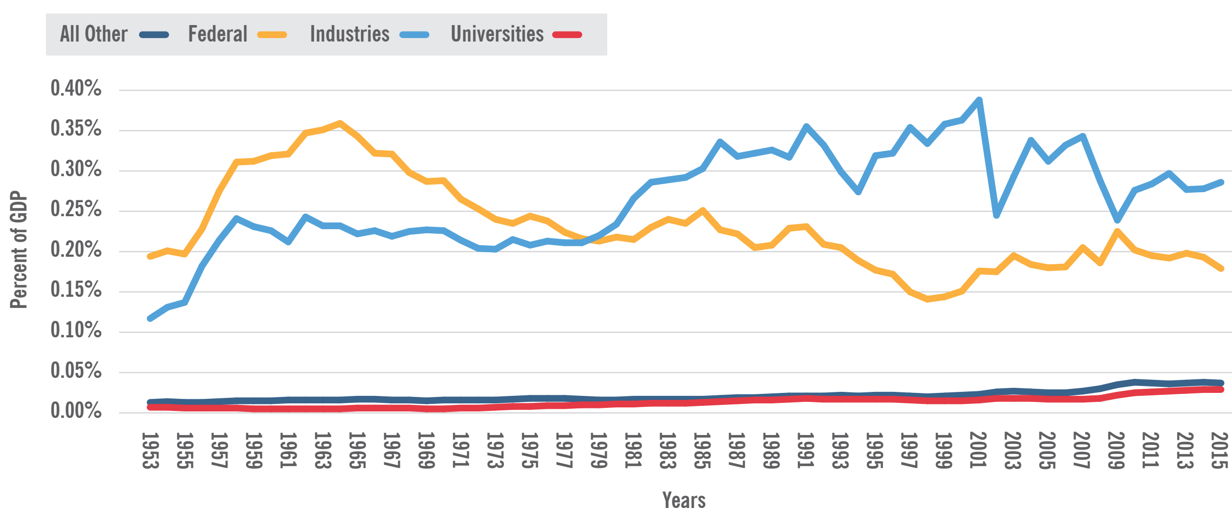
FIGURE 4. U.S. EXPENDITURES ON BASIC RESEARCH AS A SHARE OF GDP, 1953-2015



Source: American Association for the Advancement of Science, "Federal R&D Budget Dashboard." June 2018.
Available at: https://www.aaas.org/page/federal-rd-budget-dashboard

FIGURE 5. U.S. EXPENDITURES ON APPLIED RESEARCH AS A SHARE OF GDP, 1953-2015



Source: American Association for the Advancement of Science, "Federal R&D Budget Dashboard." June 2018.
Available at: https://www.aaas.org/page/federal-rd-budget-dashboard

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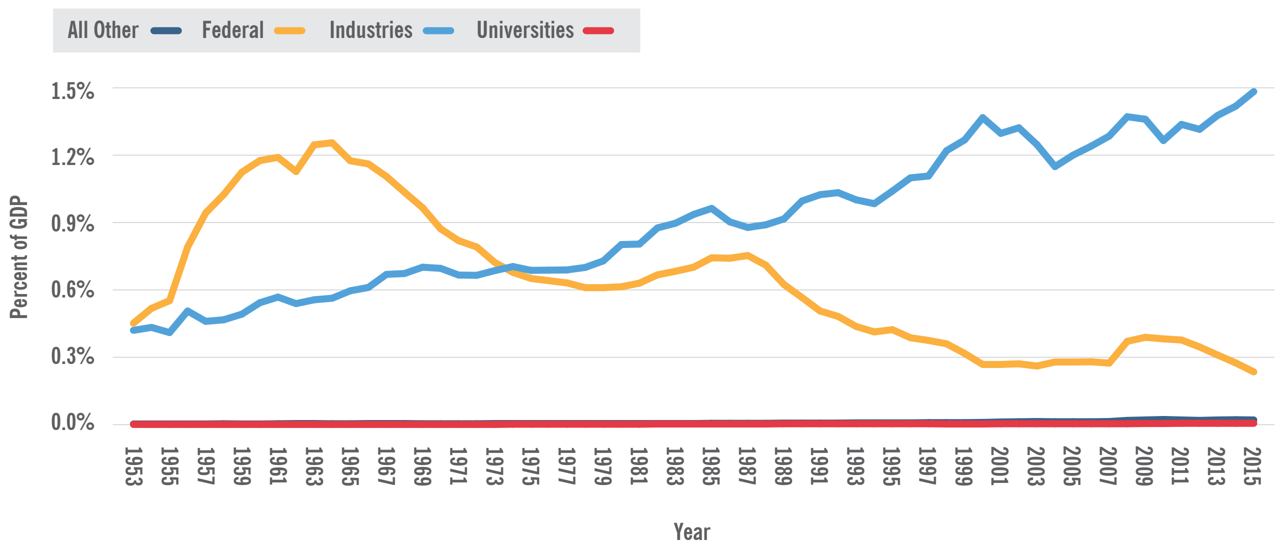
FIGURE 6. U.S. EXPENDITURES ON DEVELOPMENT AS A SHARE OF GDP, 1953-2015



Source: American Association for the Advancement of Science, "Federal R&D Budget Dashboard." June 2018.
Available at: https://www.aaas.org/page/federal-rd-budget-dashboard [37]

The United States spent 17 percent[38] of its total R&D funds, from both public and private sources, on basic research in 2015, compared with 20 percent on applied research and 64 percent on development. China spent roughly 5 percent of its total R&D funds on basic research and most of the rest on development in the same year. However, recognizing the opportunity of spearheading technology breakthroughs, the Chinese government nearly doubled[39] its public spending on basic science between 2011 and 2016, and it plans to continue expanding its early-stage research programs. The South Korean government likewise announced plans to double[40] its budget for basic research by 2022 and has already increased basic research spending over 50 percent between 2010 and 2015. By contrast, U.S. government spending on basic research declined 2.7 percent[41] over the same period. The pace with which other nations are scaling up their foundational public R&D investments presents serious threats to America's ability to develop game-changing technologies if it doesn't follow suit (Figure 7).

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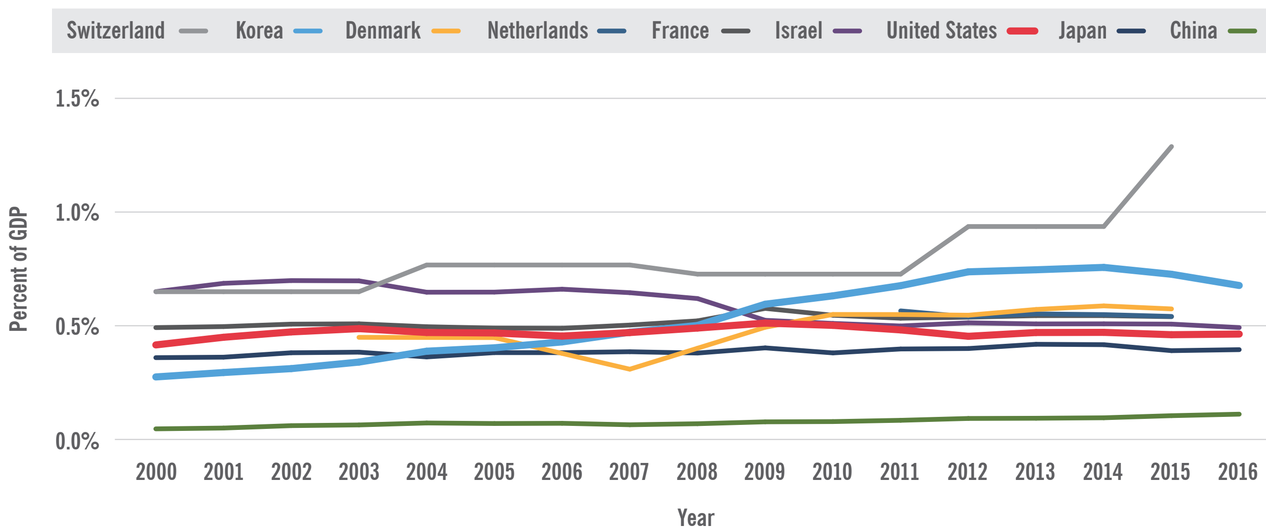
FIGURE 7. BASIC RESEARCH EXPENDITURES AS A PERCENT OF GDP



Source: AEIC Generated. Data Source: OECD. Main Science and Technology Indicators. Basic research expenditure as a percentage of GDP. Available at: https://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB [42]
Note: Data for Denmark and Switzerland is not reported every year. For years when data was not available, linear interpolation was used to estimate data for off years.

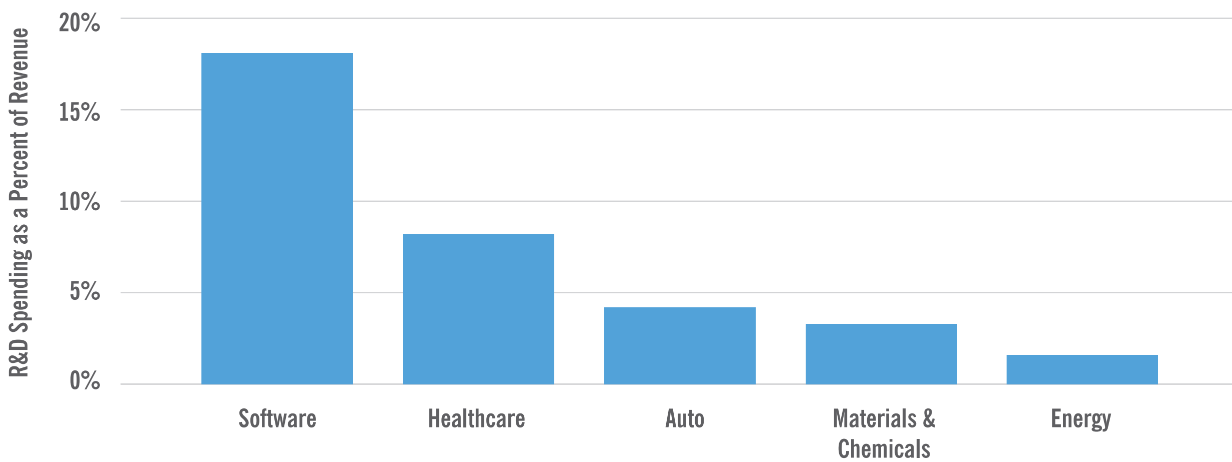
While U.S. businesses have demonstrated remarkable success in supporting late-stage R&D and commercializing new technologies to fill market needs, there is still a gap in late-stage R&D that the private sector is not filling. Today's business models are not well-suited to supporting high-capital-cost, time-intensive, high-impact R&D projects—whether early- or late-stage—even if they can have an outsized benefit for the American people. These gaps are where government can be a valuable partner.

ENERGY INNOVATION IN THE UNITED STATES

U.S. ENERGY R&D TRENDS

The shift in R&D composition in the United States has had a particularly profound impact on an ability to develop the next generation of advanced energy technologies. As previously stated, energy R&D tends to be time- and capital-intensive and is subject to significant regulatory uncertainty compared with other industries. As a result, many businesses are either unwilling or unable to take on the risk of spearheading breakthroughs in energy technology and tend to underinvest in energy R&D. Energy companies spend on average just 0.3 percent[43] of revenue on energy R&D. The aerospace, electronics, and pharmaceutical industries, by contrast, spend 8.5 percent, 9.8 percent, and 21.4 percent respectively on R&D as a percent of sales.[44,45] The results of a 2017 survey[46] of the largest corporate R&D spenders illustrate that even the most R&D-heavy firms invest only a small fraction of revenue in energy R&D compared with other sectors (Figure 8).

FIGURE 8. R&D INTENSITY OF TOP 1,000 CORPORATE R&D SPENDERS, BY INDUSTRY, 2017



Source: AEIC Generated. Data Source: PwC. "The 2017 Global Innovation 1000 Study." June 2017. Available at: https://www.strategyand.pwc.com/innovation1000#GlobalKeyFindingsTabs3|VisualTabs1 [47]

The U.S. government has historically filled the gap in energy R&D investments, but federal funding has declined over the past several decades (Figure 9). While the FY 2018 budget agreement increased government R&D funding overall, federal energy R&D investments are still 26 percent[48] below the levels set in 1978, the same year DOE was established and began working with industry to fund R&D to improve natural gas extraction techniques that have since unleashed America's newly abundant supply of low-cost natural gas.

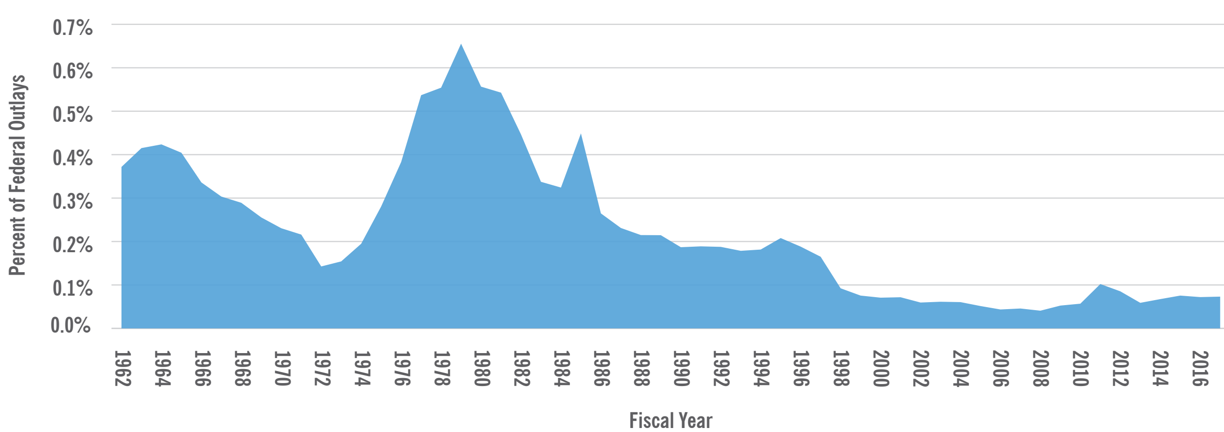
ENERGY INNOVATION IN THE UNITED STATES

The payoff of these early federal energy R&D investments has been enormous—the shale boom contributed $430 billion[49] to U.S. GDP and supported 2.7 million jobs in 2014 alone. It also enabled the United States in 2017 to become a net exporter of liquefied natural gas for the first time in 60 years.[50] *However, these achievements came about because of investment decisions made decades ago,* and it is crucial to restore funding for energy R&D as an investment in America's future.

"Tracing the development of many modern energy technologies—including solar panels, wind turbines, advanced combustion engines, and cost-saving LED light bulbs—it becomes clear that both public- and private-sector investments are crucial to facilitating the development of energy technologies across the innovation cycle."

—Dr. Wanda M. Austin

FIGURE 9. ENERGY R&D AS A PERCENT OF FEDERAL OUTLAYS, 1962-2017



Source: American Association for the Advancement of Science, "Federal R&D Budget Dashboard." June 2018. Available at: https://www.aaas.org/page/federal-rd-budget-dashboard [51]

INNOVATOR SPOTLIGHT: STRATI

Strati debuted in 2014 as the world's first 3D printed electric vehicle developed by Local Motors in collaboration with Cincinnati Incorporated and Oak Ridge National Laboratory (ORNL). The project used a large-scale, big-area additive manufacturing machine developed by ORNL and Cincinnati Inc. to print the vehicle. Their machine printed Strati in just 44 hours from a strong, inexpensive, and versatile carbon-fiber-reinforced plastic developed by ORNL. Since Strati was successfully manufactured and test-driven, Local Motors has continued to work with these partners on other projects, including Olli, which became the world's first self-driving, electric, 3D-printed shuttle bus, which began testing on college campuses in mid-2018. In January 2018, Local Motors secured over $1 billion in financing to develop Olli, in no small part because investors recognized the potentially transformative benefits of 3D printing in the auto industry:

AFFORDABILITY: Conventional vehicle design and manufacturing processes are expensive and time-intensive.

EASY AND INEXPENSIVE REPAIRS: 3D printing can reduce the number, complexity, and modularity of component parts, simplifying the repair process.

CUSTOMIZATION: Factories don't need to be entirely retooled to make design changes.

RE-USE: Vehicles can be torn down, and the materials can be used in new vehicles or products.

Strati was a landmark achievement because it demonstrated proof of concept for the use of 3D printing in large-scale automotive applications, which until then had primarily been used to manufacture smaller parts in various industries. Following Strati's success, several companies have started exploring ways to incorporate 3D printing into mass-production processes used in the mainstream automotive industry. Strati was successful in no small part thanks to its public-private structure. The project relied heavily on materials science and advanced manufacturing techniques developed at the Manufacturing Demonstration Facility housed at ORNL, which continues to work with private partners to conduct game-changing R&D, identify high-impact applications for its technologies, and bring new products to market.

Debate over the role of government versus the private sector in supporting innovation often centers on which stages of R&D each entity should undertake. Those in favor of limited government argue that the U.S. government, if it has a role at all, should be limited to supporting early-stage, basic research and that later-stage applied R&D should be left to the private sector. Yet by tracing the development of many modern energy technologies, including hydraulic fracturing,[52] advanced low-emission combustion engines,[53] and cost-saving LED light bulbs,[54] it becomes clear that the public and private sector play crucial and complementary roles across the innovation cycle.

RETURN ON FEDERAL ENERGY R&D INVESTMENTS

Advocates of limited government are rightly concerned about using taxpayer dollars wisely and avoiding wasteful spending. Yet DOE-funded R&D, both basic and applied, has been shown to generate a significant return on investment, lower energy prices for consumers, create jobs, and produce technology that improves the quality of life for Americans across the country.

> Aircraft advances are so driven by innovation as to be the lifeblood of the industry, and Gulfstream remains committed as a leader in private-sector innovation. Federal research can be a key enabler of breakthroughs that could significantly benefit the aviation industry. The U.S. funding of technology research in areas such as fuels and energy sources for aviation transport would continue to position our country as a global leader in developing new science and would complement private-sector innovation for the benefit of customers and the environment."
>
> *—Mark Burns*

INNOVATOR SPOTLIGHT: SUN4CAST

Sun4Cast is the name of a new, and significantly more accurate, solar energy production forecasting system developed by the National Center for Atmospheric Research, universities, utilities, the National Renewable Energy Laboratory, Brookhaven National Lab, and others. After receiving an award through DOE's SunShot initiative, the collaboration was able to develop a solar-forecasting system up to 50 percent more accurate than current platforms. Predicting solar irradiance has been a key barrier to incorporating greater levels of solar energy onto the grid because many atmospheric variables can hamper the ability of solar panels to harness all the energy from the sun's rays. The team's new system can forecast atmospheric variables such as cloud cover, humidity, and air quality in greater detail hours and up to days ahead. This is a game-changer because with more accurate forecasts, utilities can deploy solar energy more reliably and cost-effectively. The system is already projected to save utilities as much as $455 million through 2040 by reducing the need to purchase energy on the market. Recognizing this value, many utilities, including Xcel Energy, have already incorporated the system at their facilities.

INNOVATOR SPOTLIGHT: SUN4CAST (CONT.)

The development of Sun4Cast exemplifies the effectiveness, efficiency, and mutual benefit of conducting use-inspired research and harnessing expertise and resources from both industry and government. Groups first identified an industry need and then worked together to develop a system to meet those needs, each contributing to the development of various parts of the system. Scientists and engineers from universities and the national labs relied on the National Center for Atmospheric Research's extensive solar-forecasting research, as well as utility expertise, to build and configure the system. Thanks to their joint efforts, Sun4Cast is already beginning to be deployed and is improving the way utilities incorporate solar energy into the grid of the future.

A recent DOE report found that federal investments in building efficiency R&D from 1976 to 2015 yielded energy savings of nearly $22 billion[55] for consumers, achieving a benefit-to-cost ratio ranging from 20 to 1 to as high as 66 to 1. Likewise, federal investments in high-efficiency diesel engines totaling $931 million between 1986 and 2007 were shown to generate $70 billion[56] in economic benefits, an amazing return of $70 for every federal dollar invested. A National Academies report found that a portfolio of DOE investments in energy efficiency R&D between 1978 and 2000 generated a return of roughly $20 for every dollar invested[57], while a portfolio of fossil energy R&D programs between 1986 and 2000 received $4.5 billion in funding but generated $7.4 billion[58] in economic benefits to the United States.

Late-stage R&D initiatives funded by DOE have also generated significant benefits to the United States. DOE-funded R&D in seismic mapping, horizontal drilling, and advanced drill bits during the 1970s led to the development of hydraulic fracturing techniques that ushered in the shale revolution. Likewise, 75 percent[59] of domestic coal-fired power plants include technology with roots in DOE's Clean Coal Technology Demonstration program. The newly operational Petra Nova[60] carbon capture project in Texas also got off the ground thanks in part to a grant from DOE's Clean Coal Power Initiative, which aims to share costs with industry to develop and demonstrate advanced coal power generation technologies. These investments have benefited American consumers and businesses in every U.S. state.

> **"Innovations in energy technology benefit American consumers and businesses across the country by simultaneously facilitating long-term and stable economic growth, preserving our natural environment, and bolstering energy security."**
>
> *—Thomas F. Farrell II*

ENERGY INNOVATION IN THE UNITED STATES

Figures 10 and 11 below tabulate DOE funding for programs that span basic to applied research, as well as other programs that facilitate greater energy access, create jobs, and lower energy costs for consumers and businesses. Figure 10 reports the total discretionary funding allocated to each state from key DOE program offices, including the Office of Science, Office of Energy Efficiency and Renewable Energy (EERE), Office of Fossil Energy, and Office of Nuclear Energy. Figure 11 summarizes the total value of grants awarded to each state from DOE's EERE, Office of Science, and ARPA-E. Figure 11 includes some discretionary awards allocated to each state, as reflected in Figure 10, in addition to competitively awarded grants funded by that program office and performed in that state. While there is some overlap, the funding levels in Figure 10 and Figure 11 are separate spending streams. Much of the information in Figure 11 is publicly available but not aggregated by state and DOE program offices anywhere else.

FIGURE 10. DOE BUDGET AUTHORITY BY STATE IN FISCAL YEAR 2017

State	Overall DOE Funding (FY17)	Office of Energy Efficiency and Renewable Energy (EERE)	Office of Science (SC)	Office of Fossil Energy (FE)	Office of Nuclear Energy (NE)
Alabama	$21,407,000	$2,886,000	$1,824,000	$13,816,000	$0
Alaska	$2,322,000	$1,923,000	$0	$399,000	$0
Arizona	$129,399,000	$2,073,000	$6,059,000	$1,344,000	$0
Arkansas	$18,208,000	$2,338,000	$3,343,000	$0	$0
California	$2,877,601,000	$90,876,000	$1,332,817,000	$31,477,000	$4,050,000
Colorado	$1,156,324,000	$823,046,000	$28,566,000	$8,270,000	$0
Connecticut	$13,251,000	$3,001,000	$7,098,000	$1,293,000	$0
Delaware	$6,707,000	$839,000	$5,380,000	$488,000	$0
Florida	$22,362,000	$3,250,000	$9,159,000	$0	$0
Georgia	$87,205,000	$4,107,000	$7,990,000	$8,513,000	$0
Hawaii	$2,771,000	$488,000	$2,183,000	$0	$0
Idaho	$1,395,790,000	$35,112,000	$4,685,000	$626,000	$711,316,000
Illinois	$1,174,344,000	$78,002,000	$992,932,000	$12,614,000	$36,550,000
Indiana	$26,070,000	$7,097,000	$18,973,000	$0	$0

ENERGY INNOVATION IN THE UNITED STATES

FIGURE 10. DOE BUDGET AUTHORITY BY STATE IN FISCAL YEAR 2017 (CONT.)

State	Overall DOE Funding (FY17)	Office of Energy Efficiency and Renewable Energy (EERE)	Office of Science (SC)	Office of Fossil Energy (FE)	Office of Nuclear Energy (NE)
Iowa	$69,693,000	$7,845,000	$38,918,000	$1,752,000	$0
Kansas	$9,558,000	$2,851,000	$5,526,000	$1,181,000	$0
Kentucky	$292,224,000	$4,881,000	$1,660,000	$1,958,000	$0
Louisiana	$534,081,000	$2,115,000	$3,261,000	$0	$0
Maine	$3,224,000	$3,244,000	$0	$0	$0
Maryland	$131,709,000	$3,226,000	$10,015,000	$17,592,000	$0
Massachusetts	$65,122,000	$6,886,000	$54,815,000	$692,000	$0
Michigan	$135,520,000	$15,649,000	$119,871,000	$0	$0
Minnesota	$35,514,000	$9,939,000	$8,144,000	$0	$0
Mississippi	$2,470,000	$1,947,000	$264,000	$0	$0
Missouri	$657,167,000	$6,307,000	$7,033,000	$245,000	$250,000
Montana	$53,304,000	$2,630,000	$3,646,000	$714,000	$0
Nebraska	$42,889,000	$2,724,000	$4,419,000	$0	$0
Nevada	$506,960,000	$1,212,000	$950,000	$0	$0
New Hampshire	$3,423,000	$1,760,000	$1,663,000	$0	$0
New Jersey	$99,433,000	$5,881,000	$90,264,000	$0	$0
New Mexico	$4,798,524,000	$67,965,000	$103,234,000	$2,265,000	$36,750,000
New York	$1,236,840,000	$23,870,000	$493,407,000	$6,646,000	$2,215,000
North Carolina	$28,552,000	$4,795,000	$14,114,000	$7,257,000	$0
North Dakota	$112,141,000	$2,604,000	$150,000	$16,972,000	$0
Ohio	$490,581,000	$14,100,000	$13,763,000	$6,287,000	$0
Oklahoma	$42,437,000	$2,975,000	$1,987,000	$5,190,000	$0
Oregon	$5,280,000	$3,190,000	$1,915,000	$175,000	$0
Pennsylvania	$580,345,000	$15,210,000	$20,462,000	$19,495,000	$0
Rhode Island	$5,527,000	$1,392,000	$4,130,000	$5,000	$0

ENERGY INNOVATION IN THE UNITED STATES

FIGURE 10. DOE BUDGET AUTHORITY BY STATE IN FISCAL YEAR 2017 (CONT.)

State	Overall DOE Funding (FY17)	Office of Energy Efficiency and Renewable Energy (EERE)	Office of Science (SC)	Office of Fossil Energy (FE)	Office of Nuclear Energy (NE)
South Carolina	$2,035,547,000	$3,362,000	$4,937,000	$0	$3,500,000
South Dakota	$62,505,000	$2,046,000	$436,000	$0	$0
Tennessee	$3,280,595,000	$113,816,000	$917,383,000	$2,950,000	$86,880,000
Texas	$801,372,000	$7,481,000	$22,659,000	$8,338,000	$0
Utah	$70,985,000	$2,359,000	$1,234,000	$0	$0
Vermont	$2,017,000	$1,490,000	$527,000	$0	$0
Virginia	$167,307,000	$4,619,000	$127,432,000	$1,641,000	$0
Washington	$3,055,808,000	$81,357,000	$170,003,000	$10,951,000	$12,580,000
West Virginia	$684,835,000	$180,660,000	$0	$407,145,000	$0
Wisconsin	$47,302,000	$8,955,000	$38,347,000	$0	$0
Wyoming	$18,179,000	$1,353,000	$405,000	$1,186,000	$0

Source: Department of Energy. FY 2018 Congressional Budget Request. May 2017.
Available at: https://www.energy.gov/sites/prod/files/2017/05/f34/FY2018BudgetStateTable_0.pdf [61]
Note: Figure 10 displays total program office funding, which reflects discretionary spending allocated to each state (i.e. the state energy program, weatherization assistance program, etc.).

ENERGY INNOVATION IN THE UNITED STATES

FIGURE 11. NUMBER AND VALUE OF GRANTS AWARDED TO EACH STATE FROM KEY DOE OFFICES

State	Number of EERE Grants (FY17)	Total EERE Grant Funding (FY17)	Number of SC Grants (FY17)	Total SC Grant Funding (FY17)	Number of ARPA-E Grants (cumulative)*	Total ARPA-E Grant Funding (cumulative)*
Alabama	10	$4,133,690	9	$2,839,654	2	$2,209,605
Alaska	11	$4,849,198	0	$0	1	$497,133
Arizona	11	$3,931,832	17	$7,917,403	16	$51,456,255
Arkansas	5	$4,002,598	4	$914,118	4	$8,486,416
California	47	$23,899,149	211	$188,006,687	157	$402,165,619
Colorado	16	$11,736,596	63	$29,154,239	37	$107,879,142
Connecticut	9	$4,074,184	14	$6,640,393	39	$92,830,907
Delaware	4	$919,221	11	$7,419,386	7	$21,343,765
Florida	20	$11,682,094	27	$11,049,210	10	$33,384,421
Georgia	12	$12,641,274	16	$7,303,595	13	$26,014,813
Hawaii	4	$995,775	9	$3,238,286	2	$1,495,977
Idaho	6	$1,706,009	1	$395,312	0	$0
Illinois	13	$25,284,509	71	$35,478,536	34	$89,138,066
Indiana	10	$6,759,185	27	$15,922,922	9	$23,962,317
Iowa	4	$5,484,119	9	$4,488,816	7	$12,390,758
Kansas	3	$3,003,032	8	$4,811,482	2	$2,574,335
Kentucky	6	$5,504,572	10	$2,399,767	5	$7,993,204
Louisiana	7	$2,501,780	8	$3,203,073	1	$3,299,936
Maine	8	$49,042,240	0	$0	2	$3,572,090
Maryland	8	$5,920,146	36	$18,253,886	19	$41,987,482
Massachusetts	17	$17,566,395	117	$64,935,128	63	$177,092,803
Michigan	18	$35,937,704	49	$123,361,378	24	$68,475,043
Minnesota	8	$13,191,363	16	$9,942,999	9	$24,048,196
Mississippi	2	$2,043,330	3	$1,420,000	2	$999,999
Missouri	7	$7,015,977	14	$9,814,352	8	$33,645,514
Montana	5	$3,237,888	4	$3,145,675	1	$2,556,529
Nebraska	7	$3,856,497	4	$1,863,998	2	$3,343,299

FIGURE 11. NUMBER AND VALUE OF GRANTS AWARDED TO EACH STATE FROM KEY DOE OFFICES (CONT.)

State	Number of EERE Grants (FY17)	Total EERE Grant Funding (FY17)	Number of SC Grants (FY17)	Total SC Grant Funding (FY17)	Number of ARPA-E Grants (cumulative)*	Total ARPA-E Grant Funding (cumulative)*
Nevada	3	$2,170,249	4	$447,220	1	$2,342,430
New Hampshire	3	$1,898,037	4	$1,781,965	2	$2,997,424
New Jersey	8	$7,188,857	27	$13,297,857	9	$16,673,254
New Mexico	6	$2,613,744	23	$6,454,360	14	$39,554,483
New York	31	$92,748,398	95	$47,770,206	34	$64,797,556
North Carolina	15	$14,081,158	27	$16,356,797	18	$55,959,583
North Dakota	2	$2,759,719	1	$149,590	1	$471,353
Ohio	14	$57,119,665	39	$15,295,123	20	$58,062,622
Oklahoma	8	$3,561,177	5	$1,545,276	2	$2,684,453
Oregon	16	$43,731,679	5	$1,413,999	7	$17,055,647
Pennsylvania	14	$23,032,728	56	$28,222,688	19	$44,111,175
Rhode Island	4	$2,051,040	23	$5,138,598	1	$3,465,143
South Carolina	6	$2,555,359	12	$4,618,163	5	$15,525,234
South Dakota	2	$2,161,236	3	$636,731	0	$0
Tennessee	12	$13,009,177	31	$15,325,431	18	$38,891,368
Texas	25	$24,605,561	60	$29,054,535	28	$74,952,754
Utah	8	$6,303,284	16	$3,905,661	13	$36,349,517
Vermont	6	$4,827,777	3	$406,032	1	$1,890,735
Virginia	11	$9,314,394	41	$16,091,500	10	$17,489,250
Washington	16	$18,421,283	39	$19,913,112	26	$68,084,693
West Virginia	9	$6,442,053	5	$1,524,238	3	$4,249,996
Wisconsin	11	$12,393,807	28	$43,517,030	9	$17,797,771
Wyoming	8	$2,932,029	4	$3,102,956	0	$0

Source: Data Source: USA Spending. Available at: https://www.usaspending.gov/#/ and ARPA-E. Available at: https://arpa-e.energy.gov/?q=project-listing. [62,63]
*ARPA-E awards are cumulative from 2009 to December 2017. EERE and SC awards are from fiscal year 2017 only.
Note: Data for grants from DOE's Office of Nuclear Energy and Fossil Energy were incomplete and are not represented here.

INNOVATOR SPOTLIGHT: GREENTOWN LABS

Greentown Labs is the largest cleantech startup incubator in the United States that works with private partners as well as local, state, and federal government entities to develop innovations in energy hardware. While advances in software can improve energy efficiency and dispatch, Greentown Labs recognizes that to create new sources of energy, upgrade and replace energy-inefficient machinery, and reduce leakage in aging infrastructure, advances in energy hardware are crucial. The incubator provides physical space for startups to build and test prototypes; encourages sharing tools, advice, ideas, and resources; breaks down barriers and facilitates working relationships among members; and connects members with local manufacturers and high impact partners to accelerate the commercialization of innovative products. Several Greentown Lab members are working with the Department of Energy to develop game changing innovations, including:

- SimpleFuel won the $1 million H2 Refuel H-Prize from DOE's Fuel Cell Technology Office, enabling it to export one of the first home-scale hydrogen refueling appliances—which is capable of more quickly and cost-effectively filling a vehicle than previous designs—to Japan.
- WattGlass received an award through DOE's SunShot initiative to help commercialize the University of Arkansas' anti-reflecting, anti-soiling coating to improve solar panel performance. WattGlass closed Series A funding in February 2017.

Compared to other clean energy and technology startup incubators, Greentown Labs is by far the largest and its focus on energy hardware is unique and fills a critical gap. By collaborating with other energy technology incubators and a range of industry and government partners, members have been able to leverage both public and private expertise to more effectively develop and commercialize innovative energy hardware.

DOE collaborates with industry partners, state governments, and universities across the country to develop energy technologies that grow the economy, reduce energy costs, and bolster energy security for the benefit of U.S. businesses and consumers. The decline in federal energy R&D funding undermines America's ability to continue doing so because it fills crucial gaps where the private sector cannot or will not invest. Because the innovation cycle is so interdependent and interconnected, it is crucial to increase federal investments in energy R&D to strengthen America's overall competitive posture in the billion-dollar energy technology markets of tomorrow.

GLOBAL ENERGY R&D INVESTMENT TRENDS

Energy is critical to virtually every industry in the modern global economy. As countries around the world grow and expand, global energy demand is projected to rise 30 percent[64] by 2040. Filling this demand will require significant investment to avoid energy supply limitations,[65] particularly in more efficient, lower-cost, and cleaner advanced energy technologies.

Total energy investment worldwide was over $1.7 trillion[66] in 2016, accounting for 2.2 percent of global GDP, and investment will continue to grow. Much of this investment was in advanced energy technology, which grew 24 percent[67] since 2011 to a total of $1.4 trillion across market segments ranging from electricity generation to manufacturing equipment to advanced fuel production and delivery. Advanced energy industries generated $200 billion[68] in revenue in the United States in 2016 alone. As global energy needs rise, so too will demand for lower-cost, more efficient, and lower-carbon energy technologies. Clean energy presents a sizeable opportunity to fill this need, since there is a growing[69] global appetite for cleaner energy technologies following the Paris Climate Agreement in 2015. The nations that rise to the challenge of supplying these and other advanced energy technologies will reap the benefits.

"U.S. policymakers must recognize the crucial roles that both government and businesses have and continue to play in facilitating energy innovation across the globe. Federal research, in conjunction with the private sector, is critical to supporting a range of key technologies, including hydrogen fuel cells that can provide a zero-emissions source of power, with the potential to revolutionize transport and electricity production, storage, and distribution."

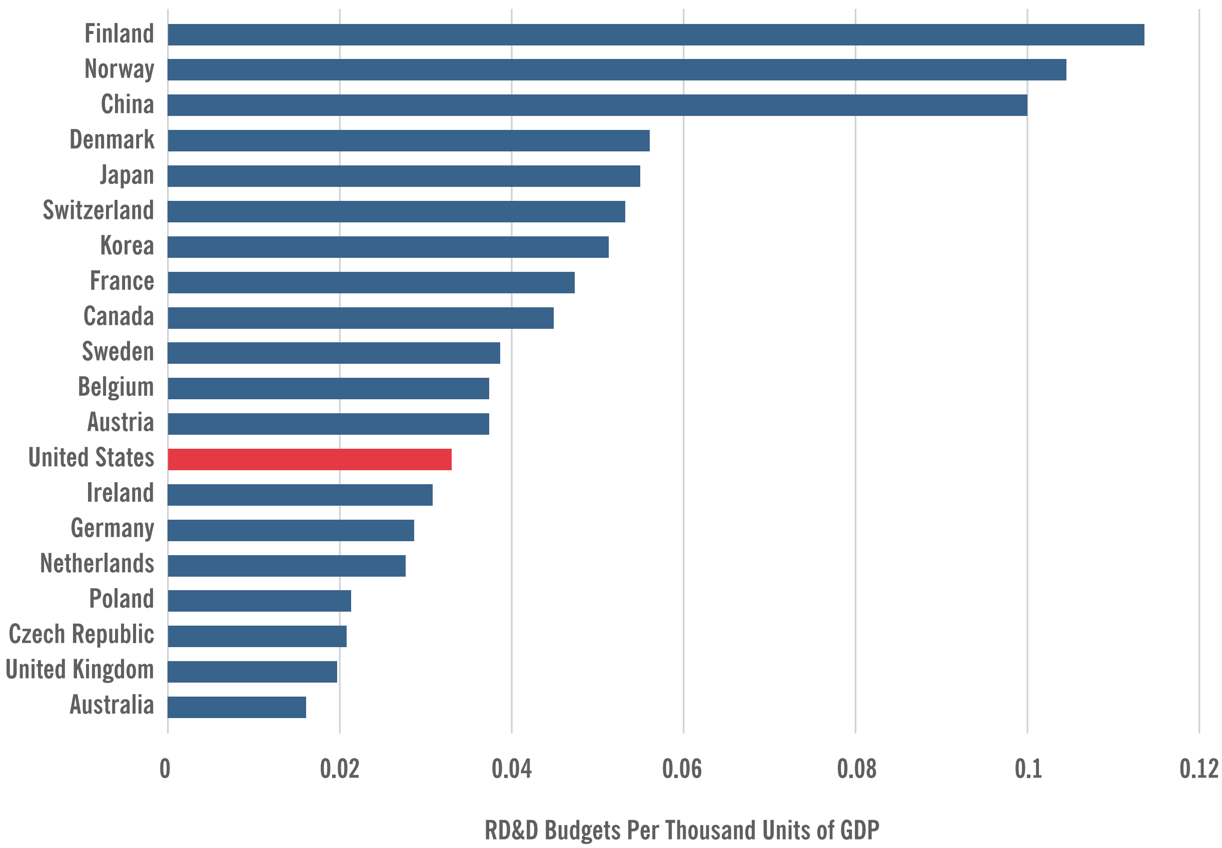
—Michael J. Graff

Global energy R&D was equally balanced between public and private sources in 2016,[70] reflecting the importance of both government and industry in facilitating energy innovation across the globe. This is a reality American decision makers must heed, particularly in light of declining U.S. federal energy R&D funding as a fraction of GDP. A significant portion of DOE's budget is spent on defense as opposed to civilian energy R&D, which makes declining public energy R&D funding in the United States even more concerning (Figure 13).

GLOBAL ENERGY R&D INVESTMENT TRENDS

China, meanwhile, has become one of the largest[71] spenders on energy R&D as a share of GDP, and the United States now trails 12 other nations in the amount of public dollars invested in energy R&D relative to GDP (Figure 12). Despite these setbacks, the United States is still well-poised to capture market share in emerging billion-dollar energy technology markets, but only if it makes the necessary R&D investments to rise to the challenge.

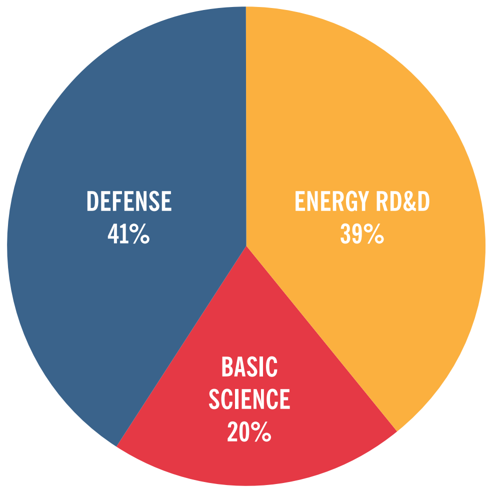
FIGURE 12. GOVERNMENT ENERGY RD&D INVESTMENT AS A PERCENTAGE OF GDP, 2015



Source: David M. Hart and Colin Cunliff. "Federal Energy RD&D: Building on Momentum in Fiscal Year 2019." Information Technology & Innovation Foundation. April 2018. Available at: https://itif.org/publications/2018/04/23/federal-energy-rdd-building-momentum-fiscal-year-2019 [72,73]
Simon Bennett and Remi Gigoux. "Declining Energy Research Budgets Are a Cause for Concern." International Energy Agency. October 2017. Available at: https://www.iea.org/newsroom/news/2017/october/commentary-declining-energy-research-budgets-are-a-cause-for-concern.html
Note: The statistic for China's public energy R&D investment includes government and state-owned enterprise spending.

GLOBAL ENERGY R&D INVESTMENT TRENDS

FIGURE 13. DOE RD&D FY 2017



Source: David M. Hart and Colin Cunliff. "Federal Energy RD&D: Building on Momentum in Fiscal Year 2019." Information Technology & Innovation Foundation. April 2018. Available at: https://itif.org/publications/2018/04/23/federal-energy-rdd-building-momentum-fiscal-year-2019 [74]

Lithium-ion batteries (LIBs)—a DOE-funded technology that now powers everything from laptops and cell phones to energy storage systems and electric vehicles—are a perfect example of a high-growth energy technology opportunity where the United States can get ahead. The global LIB market is poised to grow to $40 billion[75] by 2024. Despite the success of U.S. electric vehicle manufacturers, these companies rely on Asian nations to supply raw materials for lithium-ion battery cells, which comprise roughly 60 percent[76] of the cost of a lithium-ion battery for an electric vehicle. Today China, Japan, and South Korea lead the LIB industry and constitute 85 percent[77] of global production capacity for all end-use applications. This is a sizeable advantage, particularly as investment ramps up for markets that rely on LIBs. Over $1 billion[78] was invested in grid-scale storage in 2016, and electric vehicle sales are poised to climb 33 percent[79] between 2017 and 2018 alone and continue growing. However, experts suggest that LIBs are reaching the upper limit[80] of energy density and that new chemistries, such as solid-state batteries, will be needed to lower costs and achieve performance targets for various applications of rechargeable batteries.

GLOBAL ENERGY R&D INVESTMENT TRENDS

"Energy technologies often develop over a period of decades, so maintaining U.S. leadership in advanced energy technologies will require increasing federal energy research investments across the innovation cycle, including efforts to stimulate additional private-sector spending, particularly in early-stage development funding. For example, I believe the future for nuclear power depends on the safety and comparative economic efficiency resulting from development of ceramic materials and fast reactor technologies, which are at the early stage and require government-funded research in collaboration with the private sector."

—Neal Blue

Carbon capture and utilization is another promising opportunity. Carbon capture technology is operating successfully at pilot and commercial scales in the United States and around the world, but costs are still a barrier to more widespread deployment. There is a growing global appetite for low-carbon energy solutions, and several nations have indicated that carbon capture would be a key part of their clean energy portfolios going forward.

The global carbon capture and storage market is predicted to nearly double[81] between 2016 and 2022. The ability to sell or use carbon dioxide (CO_2) to make useful products makes the economics of these projects more appealing, and CO_2 is already considered a valuable commodity for certain uses. Today, CO_2 is used in enhanced oil recovery, and R&D is underway to produce stronger and lower-cost cement. Further, when coupled sustainably produced hydrogen, synthetic fuels, chemicals, and plastics can be manufactured directly from captured CO_2. With these envisioned applications, the market for CO_2 is expected to grow.[82] The recent expansion of the 45Q Carbon Capture Incentive, a federal tax credit for carbon capture and utilization projects in the United States, is expected to unleash $1 billion[83] in investment over the next six years—a lucrative technology market where the United States can get ahead.

GLOBAL ENERGY R&D INVESTMENT TRENDS

"New technologies and processes—such as large-scale energy storage, blockchain, carbon capture, advanced reactors, microgrids, and others—have emerged that are transforming how we produce and consume energy. These new options are upending traditional business models in the energy sector and beyond. Many of these emanate directly from federal research, often in partnership with Southern Company, the Electric Power Research Institute, and other electric utilities."

—Thomas A. Fanning

The bottom line is simple—the United States is a global energy technology leader today, but other nations are catching up *fast* and have already outpaced America in some key industries. Since energy technologies often develop along decades-long development cycles, maintaining U.S. leadership in emerging, advanced energy technologies will require immediately increasing federal energy R&D investments across the innovation cycle, making concerted efforts to stimulate additional private-sector spending and to partner with industry to facilitate deployment.

INNOVATIVE R&D ARRANGEMENTS

DOE supports high-impact R&D across all stages of technology readiness and has consistently explored ways to coordinate with the private sector and accelerate the pace of technology discovery, development, and deployment. In recent years, DOE has explored new institutional arrangements for this purpose, including ARPA-E, energy frontier research centers (EFRCs), energy innovation hubs, and a lab-embedded entrepreneurship program. Each is focused on a particular need and scope and embodies unique organizational features and practices, but all are designed to break down silos, complement ongoing R&D activities at the department, and foster greater collaboration to accelerate the development of breakthrough energy technologies.

ARPA-E

Congress authorized the creation of ARPA-E in 2007 as part of the America COMPETES Act and modeled it after the Department of Defense's DARPA (the Defense Advanced Research Projects Agency), which is credited with the creation of GPS, stealth capabilities, and the internet. ARPA-E, which was first funded in 2009, is focused on high-risk, high-reward, pre-commercial R&D projects that can transform the energy system and improve U.S. economic productivity and growth. ARPA-E is unique among other federal R&D programs in that it is designed to help researchers cross the technological valley of death with an eye toward the challenges they'll face in trying to commercialize. Selected through a competitive application process, every team receives funding for a limited time contingent on meeting ambitious project milestones. Teams that fail to meet milestones are terminated, ensuring taxpayer funds are used only on the most promising projects. In its nearly 10-year history, projects supported by ARPA-E have already attracted over $2.6 billion[84] in private-sector follow-on funding, and 71 have gone on to form new companies. ARPA-E projects have also published 1,724 peer-reviewed journal articles and secured 245 patents. ARPA-E has gained a reputation as a nimble and incredibly effective program and has been so successful that the National Academies recommended[85] DOE explore ways to adopt certain ARPA-E practices across DOE, which it has already begun to do.

ENERGY FRONTIER RESEARCH CENTERS

The EFRCs were established in DOE's Office of Science in 2009 and are designed to conduct the most basic, early-stage research to establish the scientific foundation for fundamental advances in energy technology. Research at the EFRCs is focused on addressing one or more "grand challenge" or "basic research" need identified by the scientific community that can form the basis of new technologies to be developed down the line. These include but are not limited to breakthrough advances in energy storage, carbon capture and utilization, and nuclear energy. Universities, national labs, non-profits, and private firms are all eligible to compete for awards and are encouraged to form multidisciplinary teams across organizations to share resources, expertise, and best practices.

ENERGY INNOVATION HUBS

DOE also houses four energy innovation hubs. The first of these was established in 2010, and each is focused on combining basic research with

INNOVATIVE R&D ARRANGEMENTS

engineering to accelerate the innovation process and address energy challenges that have been most resistant to traditional R&D arrangements. The hubs are actively breaking down institutional barriers between basic and applied research, and between government and industry, with a focus on bridging both the technological and commercial valleys of death. Teams comprise experts across multiple scientific disciplines, engineering fields, and technology areas and bring together talent from universities, private industry, and government labs. The four hubs operating today span DOE's Office of Science, Office of Nuclear Energy, and Office of Energy Efficiency and Renewable Energy and have already commercialized new high-impact technologies. The Critical Materials Institute (CMI) energy innovation hub, for example, seeks to ensure the United States has access to adequate supply chains for raw materials that are essential for the manufacture of products and services across the U.S. economy, and in particular for clean energy technologies. It normally takes roughly 20 years to commercialize new materials technology, but the close collaboration with industry embodied in the innovation hub structure enabled researchers at the Critical Materials Institute to develop a replacement for rare-earth elements like europium, critical for high-efficiency LEDs, in just two[86] years.

LAB-EMBEDDED ENTREPRENEURSHIP PROGRAM

DOE's lab-embedded entrepreneurship program places top entrepreneurial scientists within the national labs to conduct R&D and receive mentorship aimed at advancing the commercial viability of promising technologies. The program effectively expands access to the vast network of expertise and sophisticated resources at the national labs and provides a home to entrepreneurial scientists and engineers from across the country to advance technologies until they can succeed beyond the lab. The purpose of the program is to bridge the gap between early-stage energy research and commercial outcomes. Cyclotron Road, established in 2014, provided a template for the program, having pioneered the concept of supporting entrepreneurial research fellowships at Lawrence Berkeley National Lab. Through a competitive application process, Cyclotron Road supports awardees with a two-year fellowship, access to lab and office space, seed research funds, advisory support and mentorship, and connections to potential commercial partners and investors. The first cohorts that emerged from Cyclotron Road were so promising that two other national labs established similar programs over the past couple of years—Chain Reaction Innovations at Argonne National Lab and Innovation Crossroads at Oak Ridge National Lab. Fellows are now supported at all three programs by DOE's Advanced Manufacturing Office under the lab-embedded entrepreneurship program framework. Meanwhile, the entrepreneurial research fellowship model is gaining traction outside of DOE. For example, DARPA is now funding fellows at Cyclotron Road, and private philanthropy is supporting a similar entrepreneurial fellowship program at Cornell Tech in New York.

SURVEY OF DOE-FUNDED ENERGY R&D

Innovative R&D arrangements are making important contributions to the overall innovation ecosystem at DOE. ARPA-E, EFRCs, energy innovation hubs, and the lab-embedded entrepreneurship program each embody a series of unique institutional structures and practices to optimize and streamline energy R&D at various stages of the innovation cycle. Since energy technologies can take decades to mature, it is too soon to expect these programs, which are all less than 10 years old, to have drastically transformed the energy landscape or achieved all their goals. However, each has achieved notable successes in their relatively short lifespans, and there are a variety of tools available to measure their overall progress to date. A common way to evaluate R&D programs is to define a set of metrics and measure performance against them. This requires first identifying a program's purpose, scope, and goals; establishing metrics based on these goals; and measuring performance against these metrics.

Common metrics of success for innovation outcomes include, but are not limited to, publications and citations in peer-reviewed journals, patents awarded, subject inventions, improvement in technology readiness level (TRL),[87] new company formation, follow-on public or private-sector investment, etc. TRL is commonly used to assess the degree of development of a new technology on a scale from 1 to 9, with 1 describing technology at the basic research stage and 9 describing a technology that is deployment ready. Subject inventions refer to inventions made by a contractor while performing work under a government contract.

It is absolutely critical to consider a program's purpose when measuring outcomes, because some metrics may be better measures of success than others depending on the R&D scope. Programs focused on basic research, geared toward scientific discovery and creating new knowledge, such as the EFRCs, tend to result in peer-reviewed journal publications that can later inform the development of new technologies. By contrast, other programs focus on applied research and development, working toward the development of new products or services to address real-world problems. While these projects can also result in peer-reviewed publications, securing patents or attracting additional investment may be a better measure of success. ARPA-E has collected and published valuable information on its performance for a variety of these metrics, but less information is available about the EFRCs, innovation hubs, and lab-embedded entrepreneurship program. To better understand how these programs are performing, AEIC carried out a survey of recipients of awards from these programs and other applied energy R&D programs at DOE.

SURVEY DESCRIPTION

AEIC partnered with the Energy Futures Initiative (EFI), launched by former Secretary of Energy Ernest Moniz, to survey researchers at universities and companies that received funding from R&D programs at DOE. These include DOE's applied

SURVEY OF DOE-FUNDED ENERGY R&D

offices as well as the newer institutional arrangements described above. The goal of the survey was to examine the performance, design, and implementation of DOE-supported energy R&D and glean insights that can inform strategies and recommendations for future approaches to DOE-funded R&D.

Over 425 participants were invited to take part in an online survey administered between June 25 and July 23, 2018. Survey participants were identified as the lead managers for projects funded by:

1. an EFRC,
2. an energy innovation hub,
3. Cyclotron Road,
4. an ARPA-E project, or
5. an applied energy R&D project initiated between FY 2008 and FY 2014 and funded by a DOE R&D project grant, contract, or cooperative agreement.

The survey asked respondents to report outcomes for a variety of metrics following the completion of the project for which they were the project manager or principal investigator, including:

1. the number of publications in peer-reviewed and other journals,
2. the number of citations of their publications in scientific journals,
3. awarded patents and patent applications,
4. TRL at the beginning and end of a project,
5. technology licenses,
6. amount of public and private follow-on funding,
7. creation of new spin-off companies,
8. number of new or improved products, or
9. awards, prizes, or other forms of formal recognition.

In addition to asking respondents to report these metrics for the survey, participants were asked if DOE also required them to report outcomes from these metrics.

Plus, the survey asked respondents about best management practices to assess whether certain practices or institutional features in different DOE programs help or hinder the energy innovation process at various stages of technology readiness. Further, respondents were asked whether there were burdens or benefits associated with different funding vehicles (such as contracts, grants, or cooperative agreements). In addition, respondents were asked about how uncertainty about DOE programmatic funding impacted their planning for future energy R&D activity.

Findings are based on the results from 60 survey responses representing 36 states. The AEIC/EFI sample included responses from lead managers for projects funded by—in order from greatest to least represented—ARPA-E, the Office of Nuclear Energy (including projects in the Nuclear Energy University Program), the Office of Energy Efficiency

SURVEY OF DOE-FUNDED ENERGY R&D

and Renewable Energy, the Office of Fossil Energy, the EFRCs program, the National Energy Technology Laboratory, the Basic Energy Sciences program in the Office of Science, and Cyclotron Road. All responses were automatically anonymized.

While definitive conclusions cannot be drawn from this relatively small sample size, the surveys nonetheless yielded interesting results, and some of the observations from the response pool are described below.

HIGH-LEVEL INSIGHTS

1. **ARPA-E is performing well.** ARPA-E projects in the AEIC/EFI sample made a relatively rapid progression in TRL relative to the average project cost; reported producing a high proportion of publications and citation in peer-reviewed journals and other outlets; and were among the few in the sample to report the creation of spin-off companies, the development new or improved products, or patents awarded or pending. Respondents indicated that ARPA-E scientific and technical oversight was more rigorous than other federal R&D programs but that this oversight had a positive impact on achieving project outcomes overall.

2. **Reported assessment metrics vary by program.** No single assessment metric was reported to DOE across all programs in the sample, though all of the metrics the survey inquired about were reported by at least one program in the sample. This variation may reflect a difference in which metrics are considered valuable for assessing the progress of a project in different DOE programs.

3. **DOE scientific and technical oversight is contributing positively to achieving outcomes.** Most of the respondents in the sample across DOE-funded programs had performed research at other federal agencies and indicated that DOE scientific and technical oversight was more helpful or on par with that of other federal agencies in achieving project outcomes.

4. **Uncertainty about future DOE funding adversely impacts researchers' planning efforts.** Most of the respondents in the sample indicated that the uncertainty about the availability of DOE funding impacted their planning for current or future energy R&D efforts.

RESULTS

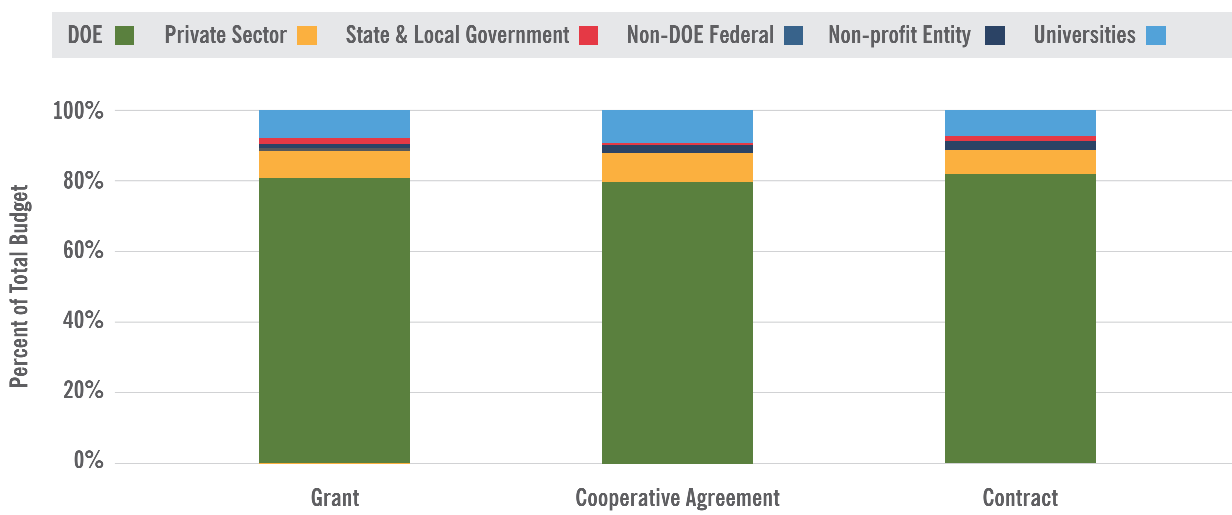
The average amount of funding provided over the life of projects among respondents was $3.23 million. The Energy Policy Act of 2005 established cost-sharing[88] requirements for most R&D activities at DOE, which requires a certain portion of the cost of an R&D project to be borne by private-sector entities. DOE generally requires a 20 percent cost-share for R&D activities, with an exemption for basic research, and a 50 percent cost-share for demonstration projects and commercial application activities.

SURVEY OF DOE-FUNDED ENERGY R&D

While there are some exceptions, higher-cost shares are generally required for later-stage R&D and demonstration projects, which is where the private sector is expected to play a larger role in deployment and commercialization. The sample reflects this. Figure 15 shows that DOE supplied 100 percent of the funding for the respondent from Basic Energy Sciences and 90 percent of the funding for the EFRCs, both of which are in DOE's Office of Science and perform basic research. Private industry supplied roughly 10 to 20 percent of the funding for R&D projects at the applied offices and ARPA-E in the sample but close to half of the funding for later-stage projects at Cyclotron Road and the National Energy Technology Lab.

As discussed above, there are differences between projects that might yield commercially valuable results in a handful of years, versus those that might only yield results on timescales longer than a decade. Similarly, there are differences between projects that require relatively small investments, versus those that require larger investments at any stage of development. The current uniformity of the cost-sharing requirements may hinder investments in higher-cost endeavors, even at the later stage, due to the higher capital risk involved for a private entity, this could be a potential area for review and reform within DOE.

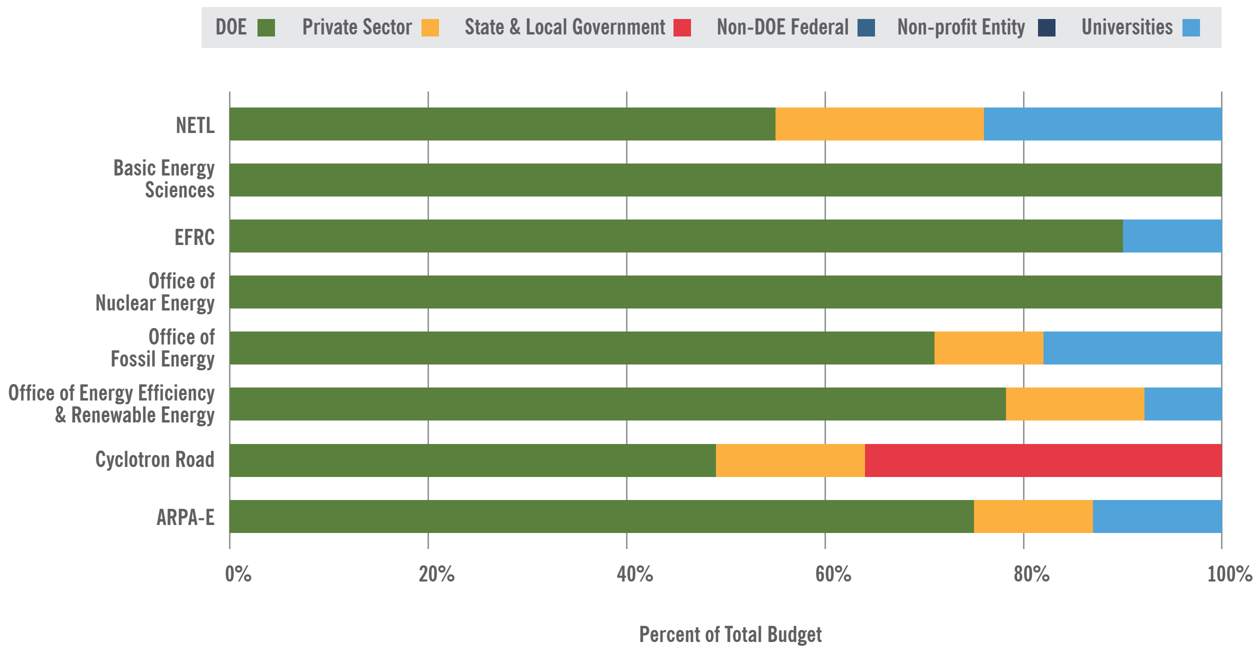
FIGURE 14. FUNDING BREAKDOWN FOR COST-SHARED PROJECTS BY FUNDING INSTRUMENT



Source: AEIC Generated Data Source: Survey launched by AEIC and EFI

SURVEY OF DOE-FUNDED ENERGY R&D

FIGURE 15. BREAKDOWN FOR COST-SHARED PROJECTS BY OFFICE



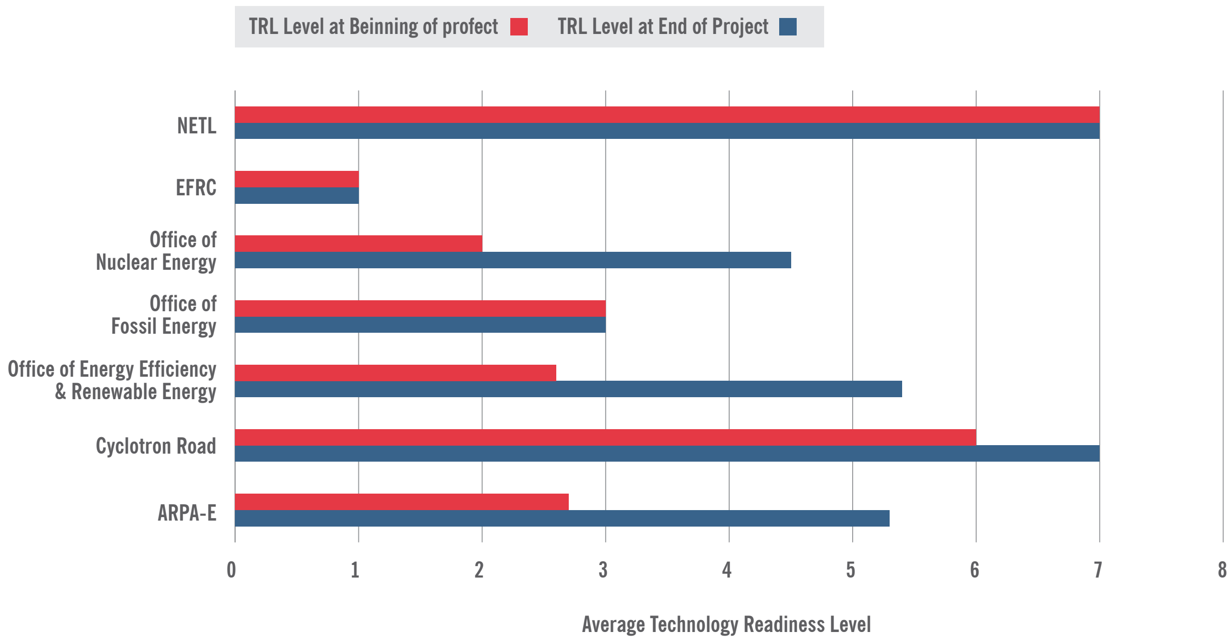
Source: AEIC Generated Data Source: Survey launched by AEIC and EFI

Figure 16 shows the average progression in TRL—which ranges from basic research at TRL level 1 through commercial-ready technology at TRL level 9—for projects in the sample. The average TRL increased noticeably over the life of projects funded by ARPA-E, Cyclotron Road, and the Offices of Nuclear Energy and Energy Efficiency and Renewable Energy in the sample. The TRL increased over the life of all ARPA-E projects in the sample, with an average increase of more than two levels. Considering that the average total cost of ARPA-E projects in the sample was $2.3 million, this reflects a relatively inexpensive cost for technology progression given the average improvement.

While definitive programmatic conclusions cannot be drawn, the trends in technology progression are consistent with expectations. ARPA-E and Cyclotron Road are designed to help energy technologies bridge the technological and commercial valleys of death, respectively. It is encouraging that projects from both programs in the sample witnessed technology progression, though it's important to point out that with such a small sample size, these may be self-selected, high-performing projects. The single EFRC project represented in the sample did not report TRL progression. This is not surprising since the EFRCs engage in early-stage basic research with the goal of generating fundamental knowledge that can underpin the development of technologies later.

SURVEY OF DOE-FUNDED ENERGY R&D

FIGURE 16. AVERAGE TRL AT THE BEGINNING AND END OF PROJECTS BY OFFICE



Source: AEIC Generated Data Source: Survey launched by AEIC and EFI

The survey also asked respondents to report the raw number of outputs for various assessment metrics—including publications and citations in peer-reviewed journals, patents, and new companies formed—and Figure 17 displays these results. As previously stated, it is crucial to consider the scope and purpose of an R&D program when evaluating project outcomes. Early-stage research projects tend to produce publications or citations because the technology or research is still so new. Late-stage research can produce publications as well, but, depending on the technology's maturity, these projects may be more capable of improving or developing products or spinning out new companies.

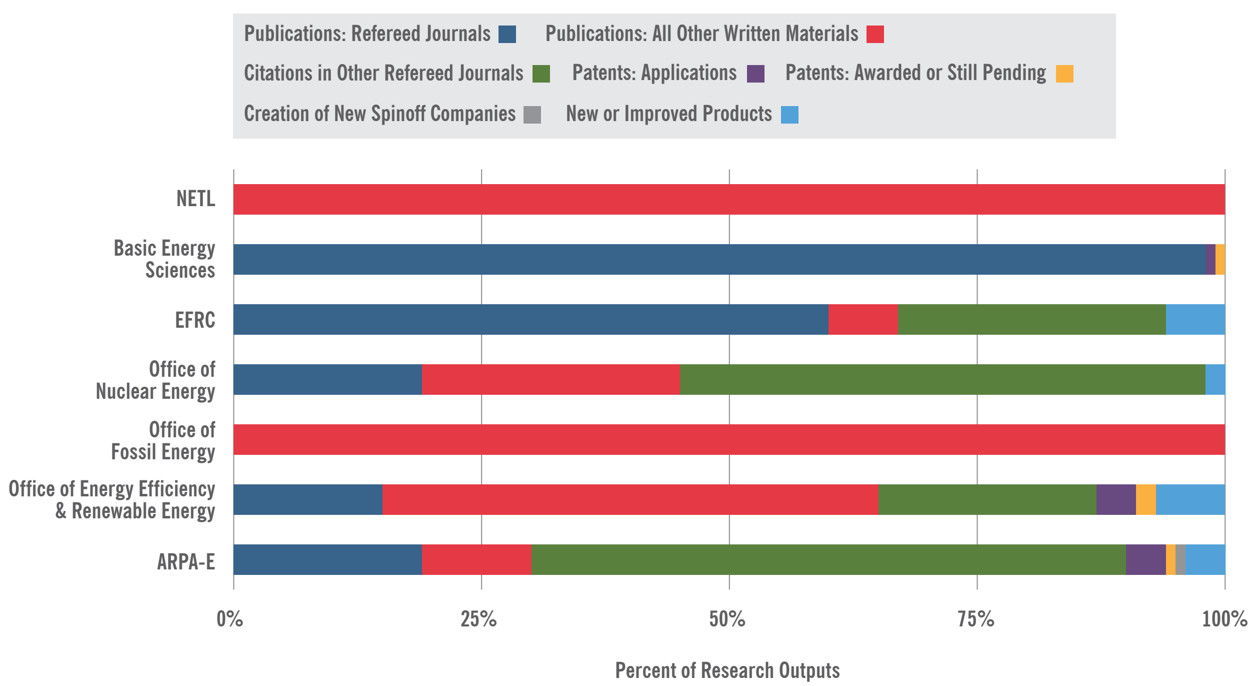
It's also important to keep in mind that some programs may choose to track some metrics and not others. This can shed light on similarities or differences in what metrics different offices report and, by extension, what metrics different offices consider valuable in assessing the progress or success of a research project. In this vein, readers should note that the absence of reported outputs for a given metric in Figure 17 below does not necessarily indicate zero outputs for that metric. Rather, the office may simply have not required projects to report outcomes for that metric.

In the AEIC/EFI sample, DOE asked projects to report all the metrics the survey identified in at least one DOE program, but no single metric was asked across all programs. Over 80 percent of respondents indicated that DOE asked them to report how many publications in peer-reviewed and other journals they produced, making publications the most

SURVEY OF DOE-FUNDED ENERGY R&D

consistently reported metric across the sample. The difference in what metrics DOE asks projects to report across offices is not necessarily a bad thing. In fact, it may reflect a tailoring of DOE oversight, as opposed to a one-size-fits-all approach, by requiring projects to report only the metrics most relevant to their scope of R&D. Still, it would be valuable to understand whether certain programs in fact produce zero outputs for certain metrics, though programs may be wary of reporting zero outputs in any category out of fear of appearing unproductive and losing funding in the annual appropriations process. While projects at various stages of development should not be expected to generate outputs for all metrics (for example, Basic Energy Sciences should not be expected to spur new companies), this is not always widely understood. Implementing uniform reporting requirements could present very real burdens and challenges for DOE researchers, and more exploration is needed on whether implementing reporting requirements for certain metrics across DOE offices would be beneficial, and which metrics, if any, it would be valuable to track.

FIGURE 17. ASSESSMENT METRICS: BREAKDOWN OF R&D OUTPUTS BY OFFICE



Source: AEIC Generated Data Source: Survey launched by AEIC and EFI

SURVEY OF DOE-FUNDED ENERGY R&D

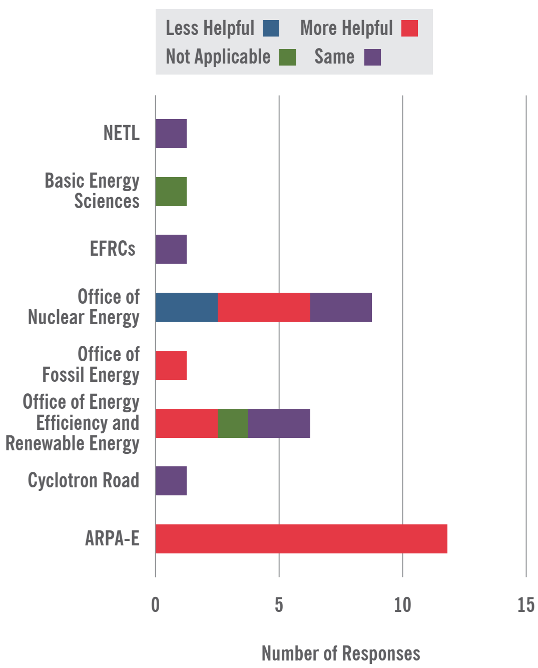
In the sample, programs focused on early-stage research—such as the Basic Energy Sciences and EFRCs programs in DOE's Office of Science—reported the highest proportion of publications and citations in peer-reviewed journals among their research outputs, as expected (Figure 17). Notably, the EFRC in the sample reported creating new or improved products, which was not expected given its focus on early-stage R&D. However, there is a wide range of products that could be included in this category, such as the development of new analytical models, databases, or other systems that advance early-stage research processes.

Projects in the sample funded by both ARPA-E and DOE's applied offices all reported producing publications in peer-reviewed journals and other outlets. ARPA-E projects also were among the few in the sample to create spin-off companies, to develop new or improved products, and to earn patents, awarded or pending. More research is needed across a larger sample to better understand how ARPA-E, the EFRCs, Cyclotron Road, and DOE's applied research programs perform against these metrics as a whole.

Respondents were asked how DOE scientific and technical oversight contributed to project outcomes compared with other DOE offices and federal agencies for which they had performed R&D. The majority of respondents had performed R&D funded by other federal agencies, and those who had not were marked as "not applicable." Responses were generally positive, as Figures 18 and 19 show. Most respondents across offices in the sample reported that DOE scientific and technical oversight was more helpful or on par with that of other federal R&D programs in achieving project outcomes. All ARPA-E projects in the sample reported that the scientific and technical oversight they received from DOE was more helpful in contributing to project outcomes, a positive reflection on the structure of ARPA-E.

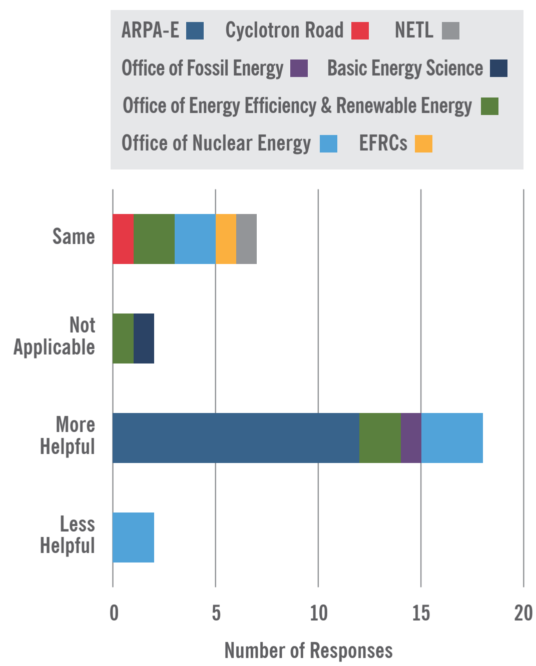
SURVEY OF DOE-FUNDED ENERGY R&D

FIGURE 18. DOE SCIENTIFIC AND TECHNICAL OVERSIGHT COMPARED TO OTHER FEDERAL R&D, BY OFFICE



Source: AEIC Generated Data Source: Survey launched by AEIC and EFI

FIGURE 19. DOE SCIENTIFIC AND TECHNICAL OVERSIGHT COMPARED TO OTHER FEDERAL R&D, BY RESPONSE



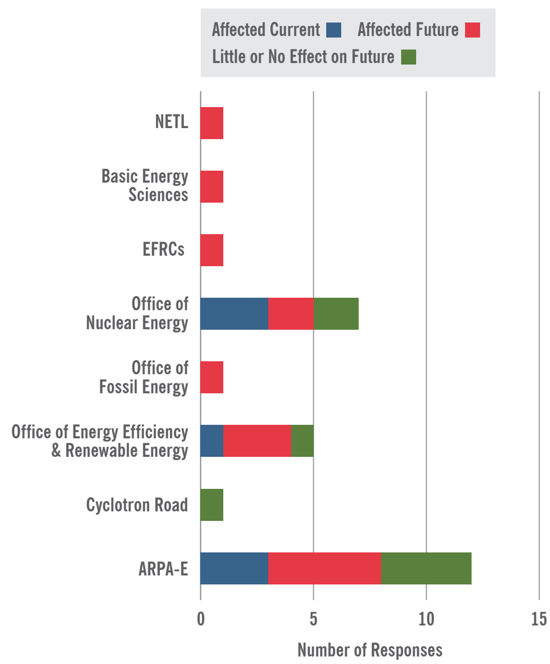
Source: AEIC Generated Data Source: Survey launched by AEIC and EFI

Respondents were also asked to what extent uncertainty surrounding appropriations for DOE energy R&D funding impacted their planning for future energy R&D efforts. There is a distinction between concerns about the continuation of an award for projects that underperform—which can be an effective way to ensure only the most promising projects continue—versus the availability of program funding at all. Program funding levels can change from year to year due to the cyclical nature of the federal appropriations process.

Uncertainty surrounding the availability of funding can delay project time lines, undermine the ability to staff project teams, and make it difficult for researchers and program managers to plan long term. Figures 20 and 21 illustrate that the majority of respondents across all offices in the survey indicated that uncertainty about DOE funding impacted their planning for current or future energy R&D efforts.

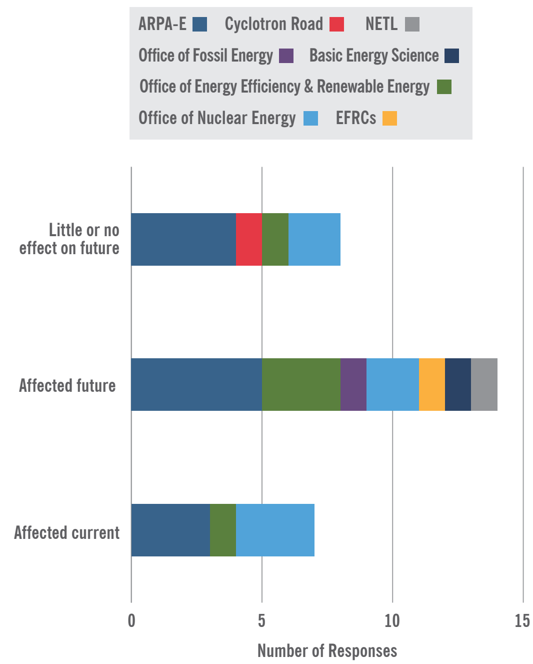
SURVEY OF DOE-FUNDED ENERGY R&D

FIGURE 20. AFFECT OF DOE FUNDING UNCERTAINTY ON PLANNING FOR FUTURE ENERGY R&D, BY OFFICE



Source: AEIC Generated Data Source: Survey launched by AEIC and EFI

FIGURE 21. AFFECT OF DOE FUNDING UNCERTAINTY ON PLANNING FOR FUTURE ENERGY R&D, BY RESPONSE



Source: AEIC Generated Data Source: Survey launched by AEIC and EFI

CONCLUSION

Energy innovation fuels America's economic engine. As nations around the world race to achieve technological leadership, the R&D investment decisions American policymakers make today will determine the nation's trajectory in the global economy tomorrow. Despite recent increases in energy R&D funding in the FY 2019 budget, U.S. federal R&D commitments remain far below the level needed to match the scale of the challenge ahead—developing the next generation of energy technologies—particularly as other nations accelerate their R&D investments.

Yet there is reason to be optimistic. Innovation is at the heart of the American spirit, and there is no shortage of examples showing that when challenges arise, the U.S. government and private industry have risen to the occasion and leveraged each other's strengths to develop many of the advanced energy technologies Americans enjoy today. Recognizing the importance of innovation to economic growth, international competitiveness, and national security, AEIC has long advocated for doubling federal energy R&D funding as an investment in America's long-term future. The business leaders who comprise AEIC recognize that government plays a vital role by filling gaps in places where the private sector underinvests. Due to long time horizons, high capital costs, and regulatory uncertainty, it is too risky for the private sector, on its own, to support fundamental advances in energy technologies that push the U.S. economy forward.

Acknowledging the relative strengths of both government and industry in the innovation process will be crucial to securing the long-term investment certainty needed to spearhead energy technology breakthroughs and ensure the nation's continued energy dominance and leadership. Innovation has been key to America's growth and success while enabling the country to overcome threats and challenges time and again. With renewed and targeted investments in energy R&D, the United States is well-positioned to seize the opportunities and face the challenges of tomorrow.

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