FY 2020 Energy Innovation Funding: Congress Should Push the Pedal to the Metal

BY COLIN CUNLIFF | APRIL 2019

Congress should elevate innovation in clean energy as a national priority, and put the U.S. back on a path to double energy research, development, and demonstration (RD&D).

In recent years, Congress has shown remarkable leadership in energy innovation policy. Rejecting the Trump administration's recommended cuts, lawmakers instead boosted funding for research, development, and demonstration (RD&D) in renewable energy, energy efficiency, carbon capture, and basic energy sciences.[1] They supported loan programs for first-of-a-kind projects, including an advanced nuclear plant and a clean methanol production facility. And they are currently debating a flurry of bills to create new programs to accelerate innovation in energy storage, atmospheric carbon removal, and advanced nuclear power.

The Trump administration has once again proposed massive cuts to energy RD&D, this time in its recently released fiscal year (FY) 2020 budget request. The Department of Energy's (DOE) RD&D budget would be slashed by more than 40 percent, from $7.3 billion in FY 2019 to less than $4 billion in FY 2020, to its lowest inflation-adjusted level since the middle of the George W. Bush administration. As a share of the economy, federal energy RD&D would reach its lowest level since the creation of DOE in 1978.[2]

Lawmakers should not give this year's budget proposal any greater credence than they have given the last two, wherein Congress emphatically rejected draconian cuts and increased energy RD&D programs by 14 percent in FY 2018 and 5 percent in FY 2019. Clean energy innovation is a win-win-win-win investment: It lowers energy costs for consumers and businesses; increases the global competitiveness of U.S. clean-tech businesses; strengthens energy security and resilience; and reduces pollution, including greenhouse gas emissions that cause climate change.

Congress should continue down the path it set in 2018 and 2019 and elevate innovation in clean energy as a national priority in 2020. The Information Technology and Innovation Foundation (ITIF) recommends Congress do the following:

- Sustain the expansion in federal energy RD&D to get the United States back on a path to doubling this investment by 2021.[3]
- Grow the Advanced Research Projects Agency-Energy (ARPA-E) budget to $1 billion within five years.[4]
- Expand the energy RD&D portfolio to cover harder-to-abate sources of carbon pollution.[5]
- Build a robust, diverse portfolio of technology demonstration projects.[6]

This report first describes the key role of the federal government in the U.S. energy innovation system. It then provides a high-level overview of both DOE's overall budget and its RD&D budget. The bulk of the report drills down into the programs and subprograms that make up DOE's RD&D budget, detailing what would be put at risk by the administration's proposed cuts, and opportunities that might be realized through expansion.

THE KEY ROLE OF THE FEDERAL GOVERNMENT IN THE U.S. ENERGY INNOVATION SYSTEM

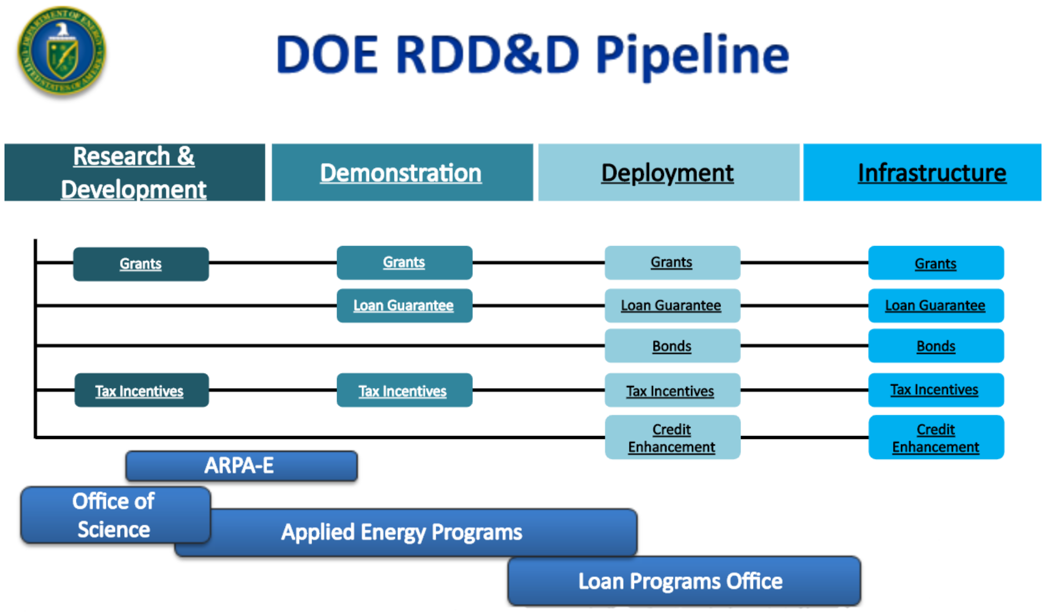
Public investment and private investment play complementary roles in the commercialization of new energy technologies. The private sector is very good at improving mature technologies and developing nearly mature ones into marketable products. It does so in response to considerations such as competitive advantage, time to market, return on investment, and other economic incentives. Industry is the primary innovator in the United States, accounting for approximately 69 percent of total research and development (R&D) spending. However, industrial innovation is by nature incremental and focused on relatively short-term payoffs.[7]

The U.S. energy industry invests a very small share of its revenues, just 0.3 percent, in R&D. That is far less than the 8.5 percent R&D-to-revenue ratio found in aerospace and defense, 9.8 percent in computers and electronics, and even 2.4 percent in autos.[8] The American Energy Innovation Council (AEIC), a group of 14 of the nation's prominent corporate leaders, has made a detailed analysis of the challenges that limit private-sector innovation in the energy sector. These include high capital-intensity and long payback periods for investments. Even venture capital (VC) funding, which tends to be less risk-averse than other sources of private capital, favors payback times and returns on investments that make it a poor match for the cleantech industry.[9]

In addition, because energy is valued as a commodity—i.e., there is no tangible difference in the electricity that comes from a coal plant versus a wind farm—emerging technologies often cannot distinguish themselves from incumbent technologies and must therefore compete on price and performance from the moment they enter the market.[10] Electric utilities are often legally mandated to keep prices low and are prohibited from investing in new technologies.[11]

The federal government is uniquely suited to address these barriers, making high-risk, long-term investments the private sector is simply unwilling to fund. Indeed, ITIF has found that federal investment frequently serves as a catalyst for industry, as government RD&D tends to attract rather than crowd out additional private RD&D dollars.[12]

Figure 1: Technology Readiness Stages of the Innovation Process[13]



Accelerating energy innovation requires a suite of policies acting together across the innovation spectrum (figure 1). For technologies that are far from commercialization, public investment in basic and applied research and technology development is necessary to improve the performance and drive down the cost of emerging technologies to the point that entrepreneurs and corporate R&D units jump in. As technologies mature, successful demonstration at commercial scale may be necessary to establish cost, reliability, and performance characteristics and provide confidence to more risk-averse investors and the public that the technology works as intended. Additional tools such as loan guarantees for first-of-a-kind commercial projects and "market pull" policies such as tax incentives and clean energy standards can bring technologies further down the cost curve. Public investment as a share of the total spent on each technology generally declines as it matures, from full public support for basic research to significant levels of private-sector cost-sharing in the development and demonstration stages to fully private funding of large-scale deployment.

As the nation's largest funder of energy RD&D, DOE fills a foundational role in the U.S. energy innovation ecosystem. Many of the technologies currently making major contributions to both the U.S. and global energy systems received DOE support along the way (See box 1**)**.

Box 1: The Shale-Gas Revolution

The shale gas revolution example illustrates the synergies of "technology push" and "market pull" policies working in concert to shepherd a new technology to market. Beginning in the late 1970s, the federal government funded fundamental research in directional drilling and shale resource characterization, countenanced and funded industry-wide collaboration in applied RD&D that might otherwise have drawn antitrust scrutiny, and subsidized industry-led demonstrations of the first horizontal wells in West Virginia and Texas. This technology push overlapped with a time-limited market-pull production tax credit for wells drilled between 1980 and 1992, with production eligible for the credit through 2002.[14] By 2002, when federal support tapered off, shale gas had grown to account for 2 percent of domestic gas production and was able to compete in the market on its own. Since then, hydraulic fracturing technologies, combined with vast domestic shale resources, have enabled shale gas to grow to 70 percent of domestic production.[15]

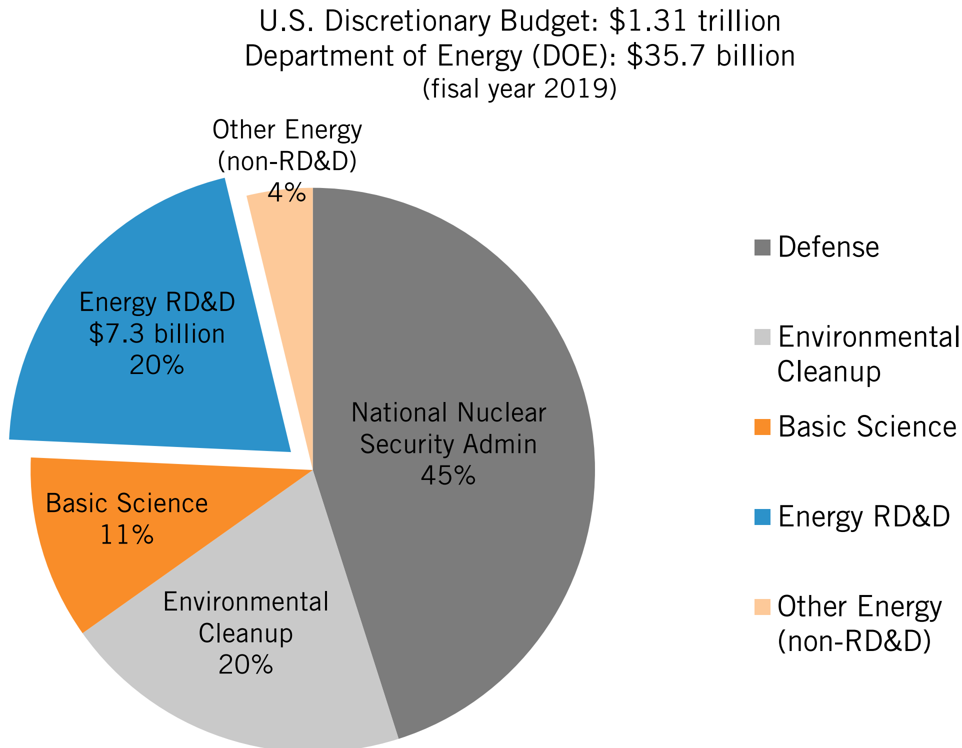
Congress has filled critical gaps in the energy innovation ecosystem through the establishment of ARPA-E and clean energy manufacturing innovation institutes, and by funding technology demonstration projects. It has also sought to build tighter linkages between DOE's national laboratories and innovators in private industry.

These hard-won gains have been threatened by the Trump administration, whose budget for FY 2020 would not merely reverse Congress's efforts to strengthen the U.S. energy innovation system, it would put the whole system at risk. Congress has definitively rejected the administration's approach in the last two budget cycles, instead providing a large boost to energy RD&D in FY 2018 and a more modest increase in FY 2019. Congress should reject the administration's FY 2020 budget proposal, elevate energy innovation as a national priority, and continue to expand federal funding for DOE's energy RD&D programs.

ENERGY RD&D: STILL A JUNIOR PARTNER AT DOE

The name "Department of Energy" may leave the mistaken impression that DOE's primary function is overseeing and improving the nation's energy innovation system. In fact, when the other activities of DOE—defense, environmental cleanup, and non-energy-focused basic science—are taken into account, only $7.3 billion, or 20 percent of DOE's budget, supports energy innovation (figure 2).

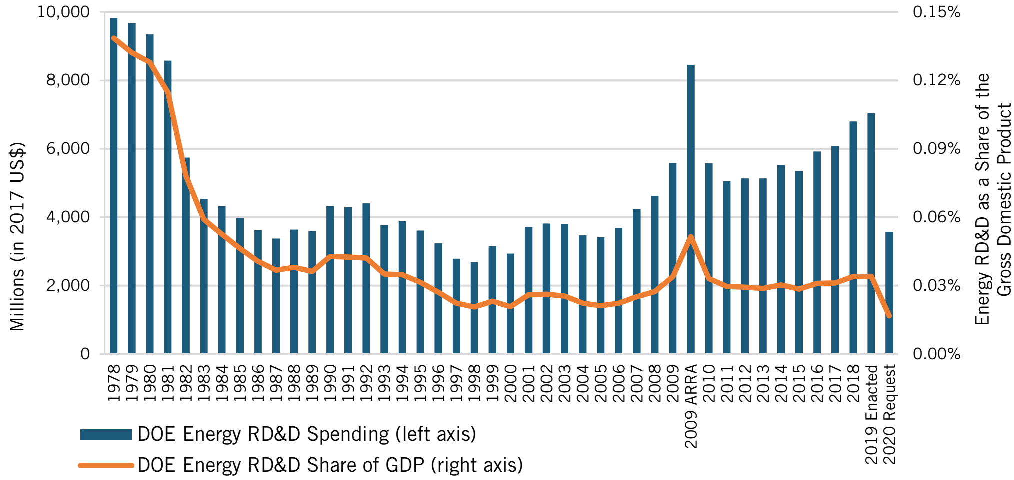
Figure 2: DOE Budget by Major Function, FY 2019[16]



DOE was created in the late 1970s at a time when energy demand was increasing rapidly, energy prices were high, and OPEC was flexing its muscles in global oil markets. Energy innovation and the development of domestic clean energy were viewed as matters of economic and national security. In 1978, Congress invested nearly $10 billion in energy research (in 2017 US$) at DOE, or more than 2 percent of non-defense discretionary spending. But as energy prices declined, energy innovation receded as a national priority—and funding for energy RD&D has not kept pace. Total funding hovered below $4 billion for most of the mid-1980s through the early 2000s (figure 3).

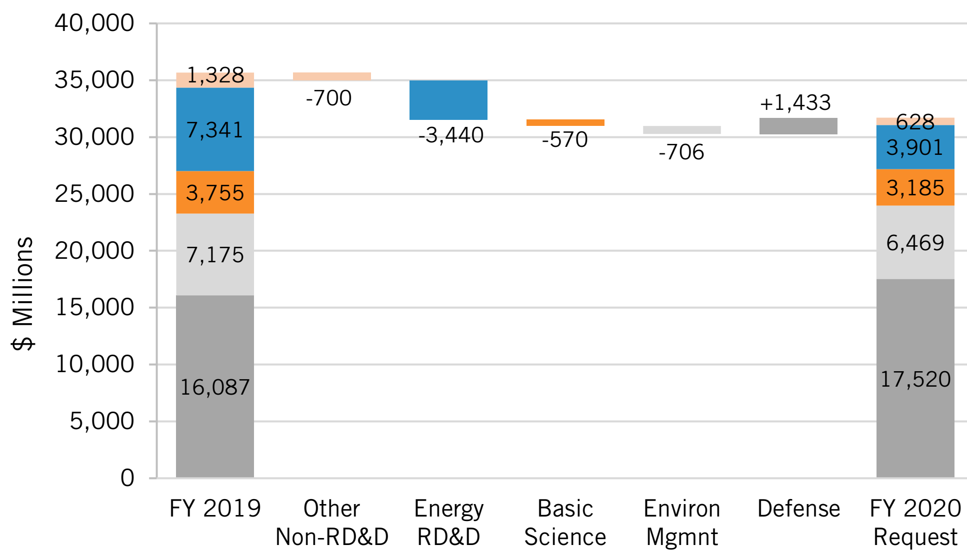
In 2007, the National Academies released its groundbreaking report *Rising Above the Gathering Storm*, which examined U.S. leadership and competitiveness in science and technology. The report concluded that without increased RD&D investments, the United States risked falling behind other nations—particularly in clean energy innovation.[17] In response, Congress passed the America COMPETES Act of 2007, which authorized a doubling of RD&D funding at DOE and other science and technology agencies. The doubling goal was reaffirmed in the 2010 reauthorization of COMPETES, and again at the launch of Mission Innovation in 2015.[18] However, actual appropriations have not matched these funding targets, and the United States remains far short of its original goal of doubling energy RD&D funding by 2021.

Figure 3: U.S. DOE Energy RD&D Spending, FY 1978 through FY 2020 Request (in 2017 US$).[19]



Yet the administration's budget proposal for DOE targets energy RD&D for its largest cuts. Figure 4 compares DOE's budget in fiscal year (FY) 2019 with the president's FY 2020 request. The president proposes a $1.5 billion increase in defense programs, while cutting environmental cleanup by 10 percent and basic science by 13 percent. The budget for energy RD&D would be cut by 48 percent, from $7.3 billion to $3.9 billion, which would reduce energy RD&D to its lowest level in real terms since 2005.

Figure 4: Proposed Changes in DOE's Budget by Major Function.[20]



ENERGY RD&D IN THE TRUMP BUDGET: HISTORIC CUTS BASED ON FAULTY PREMISES

The FY 2020 budget request, if enacted, would result in the largest single-year decrease in energy RD&D in DOE's history, and reflects a fundamental skepticism of the federal government's role in energy innovation. It is based on two flawed rationales: first, that the private sector will pick up the slack if the federal government withdraws from midand late-stage energy technology RD&D; and second, that the success of certain technologies that have seen dramatic price reductions in recent years—such as wind power, solar power, and electric vehicles—means federal action to spur further energy innovation is no longer needed.

Box 2: Dramatic Cost Reductions for Solar Photovoltaics

The evolution of solar photovoltaic (PV) technologies similarly exemplifies the role of smart public policy in accelerating innovation and the synergistic interactions between public and private investment. In the 1970s and 1980s, government and university R&D was responsible for most of the performance improvements and cost reductions in solar PV modules. During this time, the nascent solar industry was supported by the emergence in the public sector of niche applications—primarily for use in satellites—at NASA and the Defense Department that were relatively insensitive to cost. As the technology matured and the solar industry expanded, pull policies such as tax incentives, net metering, feed-in tariffs, and state portfolio standards helped expand the market for solar and also incentivized greater private-sector investment, which enabled the industry to take advantage of economies of scale. In 2011, the DOE Loan Programs Office provided loan guarantees to the first five utility-scale solar PV facilities larger than 100 megawatts (MW).[21] Thanks in large part to these policies working together in the United States and globally, the cost of solar PV panels has declined by 99 percent over the last four decades.[22]

The Office of Management and Budget (OMB) has directed agencies to focus RD&D spending on early-stage research and has issued guidance that "federally funded energy R&D should continue to reflect an increased reliance on the private sector to fund later-stage research, development, and commercialization of energy technologies."[23] The request therefore falls most heavily on the applied research, development, pilot, and demonstration projects.

Public support for emerging energy technologies is needed across the innovation spectrum in order to address market failures that typically block emerging energy technologies from reaching full maturity. Additionally, many studies have found that public investment in energy RD&D acts as a catalyst and accelerant for private RD&D. DOE itself finds that "[DOE investment] is most effective when it complements private investment, i.e. when [DOE] outputs create productive investment opportunities for the private sector, thereby crowding in private investment."[24] Unfortunately, the converse is also true: Reduced public funding will likely lead to fewer opportunities for private-sector investment in new energy technologies. Analysis by Matt Hourihan of the American Association for the Advancement of Science found that declining federal energy RD&D investment during the early 1980s contributed to decreased private RD&D in advanced energy technologies.[25]

Energy Secretary Rick Perry and other senior DOE officials have pointed to the success DOE programs in wind and solar energy have had in driving down costs as justification for budget cuts.[26] While (onshore) wind and solar PV have seen dramatic and rapid cost reductions in recent years, they are still not yet competitive without subsidies in most parts of the country.[27] More important, other emerging technologies—including offshore wind, concentrating solar power, marine and hydrokinetic power, enhanced geothermal power, algal biofuels, advanced small modular reactors, and many other clean technologies—are still far from matching the reliability and low costs of conventional technologies. Yet, these are the technologies that are targeted for the most severe cuts.

Box 3: FutureGen and Carbon Capture and Sequestration Demonstrations

Technology demonstration projects pose one of the most difficult challenges in energy innovation policy, and not all end in success.[28] The FutureGen carbon capture and sequestration (CCS) project is one such example. First proposed by President George W. Bush in 2003, the FutureGen 1.0 project was designed to demonstrate integrated gasification combined cycle electricity generation, CCS, and hydrogen production at the same site in Mattoon, Illinois. The challenge of integrating multiple new technologies at commercial scale proved costlier than originally planned, leading the Bush administration to shutter the project in 2008.

In 2010, the Obama administration revived the project as FutureGen 2.0, retaining the sequestration component of FutureGen 1.0, but calling for retrofitting an existing coal plant in nearby Meredosia, Illinois, with oxy-combustion technology. By 2011, competition from low-cost gas-powered generation resulted in the closure of the Meredosia coal plant. Challenges in securing private financing to complete construction, difficulties in obtaining environmental permits for underground carbon sequestration, and decision-making delays at DOE headquarters also contributed to the final decision to pull the plug in 2015.[29]

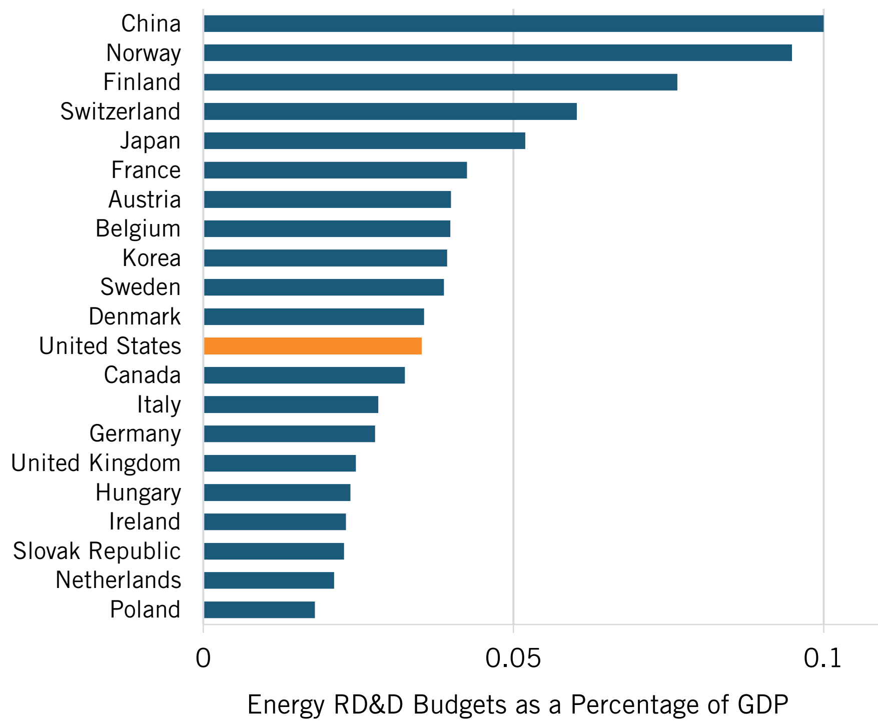
A third rationale recently offered by Acting Office of Management and Budget Director Russ Vought is that the government cannot afford to invest more in innovation when it is already running at a budget deficit.[30] However, history has shown that federal investments in energy RD&D have paid for themselves many times over in the form of lower energy costs for consumers, fewer energy imports, avoided pollution, expanded entrepreneurship, and improved competitiveness of U.S. businesses.

UNDERINVESTING IN ENERGY RD&D

By many measures, the United States is significantly *under*investing in energy innovation. At the current pace, the nation will fail to meet the climate- and competitiveness challenges of the 21st century. The recent National Climate Assessment and the Intergovernmental Panel on Climate Change's report on Global Warming of 1.5 Degrees Celsius point to the need to rapidly accelerate the clean energy transition.[31] Yet both global and U.S. carbon dioxide emissions increased in 2018.[32] The uncomfortable fact remains that clean energy technologies cannot yet match conventional fossil-fuel-based technologies in price and performance. Patent applications in clean energy have declined in recent years as well, suggesting public investment is too modest to "crowd in" private investors who would seek patent protection.[33] ITIF analysis has also identified major gaps in the federal energy RD&D portfolio, particularly from harder-to-abate sources of carbon pollution.[34]

There are warning signs that U.S. competitiveness in the global clean energy industry is at risk. Eleven other countries—including China—invest more in energy RD&D as a share of their economy than the United States (figure 5). As other countries have stepped up their investments in clean energy, the share of cleantech patents granted by the U.S. Patent and Trade Office to U.S. companies has declined, from roughly 50 percent in 2001 to less than 40 percent in 2016.[35]

Figure 5: Government Energy RD&D Investment as a Percentage of GDP, 2016[36]



For these reasons, many prominent government and industry leaders have recommended doubling or even tripling federal funding for energy RD&D. In 2018, the corporate leaders who comprise AEIC called for a federal energy RD&D budget of $16 billion annually to bring this sector closer to other advanced technology sectors.[37] In a January 2019 report, the Energy Futures Initiative (EFI), led by former Energy Secretary Ernie Moniz, noted that investing in energy RD&D at a level proportional to the current value of the energy industry to the economy ($1.37 trillion) would raise government investment to $12.5 billion per year.[38]

DOE'S ENERGY RD&D PORTFOLIO: WHAT'S AT STAKE

The energy RD&D portfolio supports 20 science and technology exploration programs that tackle a diverse set of challenges: mature domains that need to be reenergized, such as building technologies; sectors that are growing rapidly, such as solar power; cross-cutting programs that support energy systems, such as storage; and innovations yet to be commercialized, such as fusion. These science and technology programs are spread across eight program areas:

Figure 6: DOE's Energy RD&D Funding by Program Area, FY 2019

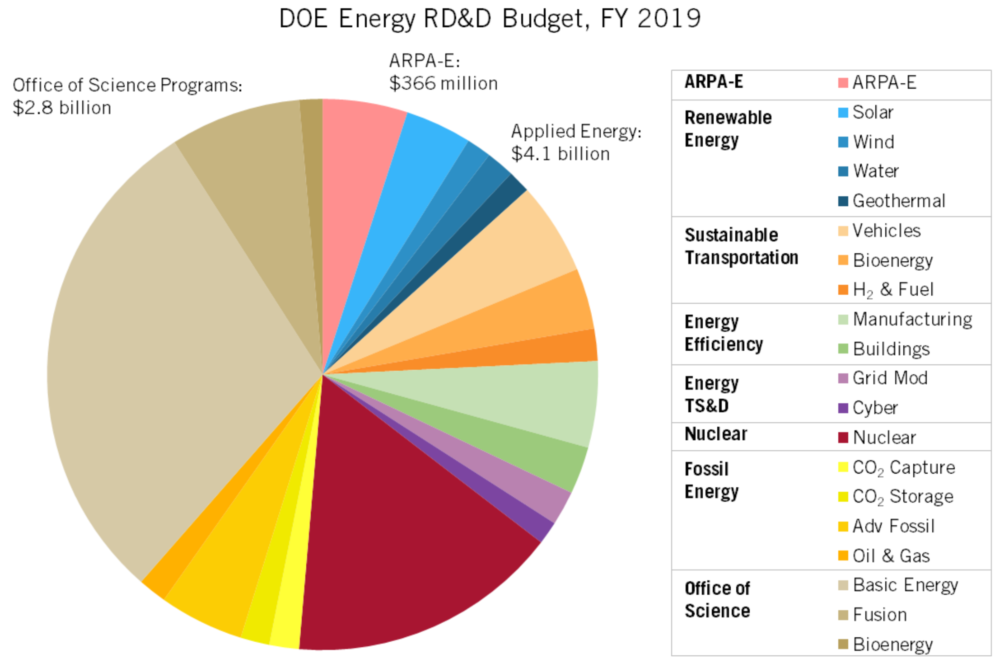


Figure 6 displays the distribution of funds across this portfolio, with programs aggregated into groups according to the DOE office that manages them. The bulk of the funding lies in DOE's applied energy offices: Energy Efficiency and Renewable Energy (EERE), which houses the programs in renewable energy, sustainable transportation, and energy efficiency; Electricity (OE); Cybersecurity, Energy Security, and Emergency Response (CESER); Fossil Energy (FE); and Nuclear Energy (NE). Within the Office of Science (SC), Basic Energy Sciences (BES), Fusion Energy Sciences (FES), and a small portion of Biological and Environmental Research (BER) that supports the bioenergy research centers are also included in DOE's energy RD&D portfolio. ARPA-E is a stand-alone, semiautonomous agency that advances cross-cutting research in high-potential, high-impact energy technologies that are too early for private-sector investment.

DOE-funded RD&D through these programs has already generated a significant return on investment. A retrospective assessment by the National Academies found that DOE investments in RD&D have helped keep energy costs low while at the same time reducing pollution, creating new business opportunities for the energy industry, and decreasing U.S. reliance on foreign oil and other energy imports.[39] More recently, an external review of energy efficiency and renewable energy RD&D programs at DOE found that taxpayer investments between 1975 and 2015 totaling $12 billion yielded more than $388 billion in net economic benefits, a remarkable return of over $32 for every federal dollar invested.[40] And ARPA-E's high-risk/high-reward ventures are already yielding big returns, including the formation of 71 new technology companies that have attracted more than $2.6 billion in private-sector follow-on funding.[41] But not all RD&D projects end in the successful commercialization of new technologies. Demonstrating complex systems, in particular, has proven especially challenging, prompting calls to reform how DOE manages demonstration projects (box 3).[42]

Figure 7: Proposed Changes in the DOE Energy Budget by Program Office[43]

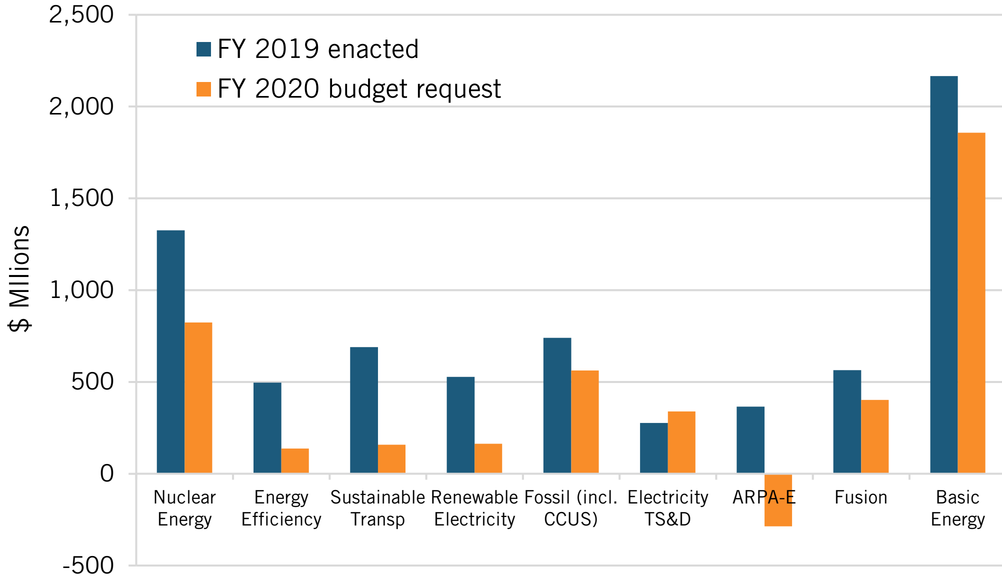


Figure 7 displays the proposed changes by DOE program offices. The proposed cuts would hit ARPA-E and the applied energy programs hardest, with ARPA-E being completely eliminated. Additionally, the budget would rescind $287 million in previously appropriated funding, taking advantage of ARPA-E having been slow to spend all the funds appropriated to it by Congress for FY 2018 and FY 2019. The Government Accountability Office found that the Trump administration had deliberately and unlawfully withheld ARPA-E from spending its FY 2017 appropriation—and this pattern may have been repeated in the last two years.[44] The Natural Resources Defense Council found that, as of December 10, 2018—more than two months after the end of fiscal year 2018—ARPA-E had been unable to spend some $280 million (79 percent) of its $353 million FY 2018 research budget, and had not even begun to spend its FY 2019 RD&D budget.[45]

The budget request for the energy efficiency, renewable energy, and sustainable transportation programs within EERE is identical to the president's proposal for FY 2019, with cuts ranging from 57 percent for water power to 82 percent for bioenergy technologies. However, the FY 2020 EERE budget makes use of the same budgeting gimmick being applied to ARPA-E: It would draw on $353 million in previously appropriated but unspent funds from FY 2018 and FY 2019 to meet the FY 2020 proposed funding level of $696 million. EERE funding would decline by 86 percent under the administration's proposal, from nearly $2.4 billion in FY 2019 to just $343 million in FY 2020.

Box 4: Pollution Control

Federal investments in pollution-control technologies provide an example of the multiple benefits of energy RD&D. Prior to DOE's coal RD&D programs, flue gas desulfurization (FGD) systems (a.k.a. "scrubbers") were costly to build and maintain, incurred substantial energy costs to run, and produced a sludge waste that required considerable land use for proper disposal. Advancements in pollution control helped drive capital and operating costs down by nearly 50 percent, kept energy costs low, and turned the waste from FGD scrubbers into valuable byproducts such as wallboard-grade gypsum.[46] DOE investments in FGD scrubbers resulted in over $50 billion in savings from public health benefits and lowered FGD costs, and also helped turn America into a global leader in environmental technologies.[47] Environmental technologies and services contribute to a trade surplus, yielding net exports of nearly $27 billion annually.[48]

Although the administration's policy often favors fossil energy, it does not spare FE, which would receive a 24 percent cut to its RD&D programs. These cuts are distributed unevenly. The largest would hit pollution-control programs, including carbon capture, utilization, and storage technologies (65 percent), and technologies to reduce methane emissions from natural gas systems (targeted for elimination). The proposal continues the administration's efforts to revitalize the coal sector, increasing R&D spending aimed at improving the thermal efficiency of existing coal power plants and the design of new "high-efficiency and low-emission" coal-fired power plants.

Notwithstanding recent Congressional efforts to jumpstart RD&D in advanced nuclear technologies, NE would be cut by 38 percent. The proposed cut comes just weeks before the reintroduction of the Nuclear Energy Leadership Act, a bipartisan bill that would refocus DOE RD&D on advanced non-light-water reactor technologies, which have the potential to play a significant role in a future low-carbon electricity system.[49]

OE and CESER are the only winners in the administration's budget request. OE's RD&D programs would receive an 18 percent boost overall, with most of that increase going to its transmission reliability and resilience program. CESER would get a 30 percent boost, with most of the increase going to non-RD&D programs aimed at securing energy infrastructure and providing emergency response.

Within SC, BES would incur a 14 percent cut, while fusion would be cut by 29 percent. BER, which houses the bioenergy research centers, would face a 30 percent cut.

For the full breakdown by RD&D programs, see table 1 in the appendix.

THE ENERGY AND CLIMATE BENEFITS OF DOE'S RD&D PORTFOLIO

What are the prospective benefits of DOE's energy RD&D portfolio, and what is at risk if funding is cut per the Trump administration's budget request? These are key questions lawmakers must grapple with as they consider how to allocate funding in the coming years.

For each of its applied energy programs, DOE sets technology cost and performance targets based on the RD&D activities possible at a given budget level. As part of its goal-setting

process, DOE, along with laboratory experts, assesses the ability of its program activities to improve a technology's characteristics (e.g., capital cost) and move it closer to commercialization. In conducting this analysis, DOE assumes funding levels will remain constant over time.

Box 5: Advances in Diesel Engines

DOE established the Combustion Research Facility in 1981 and the Advanced Combustion Engine R&D program in 1986 to improve U.S. energy efficiency, reduce energy costs to consumers and businesses, and decrease the United States' dependence on foreign oil. These initiatives brought together researchers at national labs, universities, and private companies such as General Motors, Ford, Cummins, Caterpillar, and General Electric. Between 1986 and 2007, public RD&D investments in these two programs totaled $931 million, while improved fuel economy resulting from these programs saved the U.S. trucking industry 17.6 billion gallons of diesel fuel, which translated into $34.5 billion in reduced fuel expenditures and $35.7 billion in health and environmental benefits from lower pollution. In other words, an investment of $931 million, over a period of 21 years, resulted in benefits of more than $70 billion, a return on investment of more than 70 to 1.[50]

Perhaps the best-known target was set by DOE's SunShot Initiative. which seeks to reduce the average nationwide unsubsidized cost of electricity from utility-scale solar PV to $30 per megawatt-hour (MWh) by 2030.[51] That would be below the levelized cost of electricity from a natural gas combined-cycle power plant, which was $42–78/MWh in the United States in 2017.[52] Achieving these price reductions could result in solar energy meeting 14 percent of U.S. electricity needs by 2030 (up from less than 2 percent in 2017), support 290,000 new solar jobs, and translate into $30 billion in annual energy cost savings by 2030.[53]

Other notable DOE technology targets include:[54]

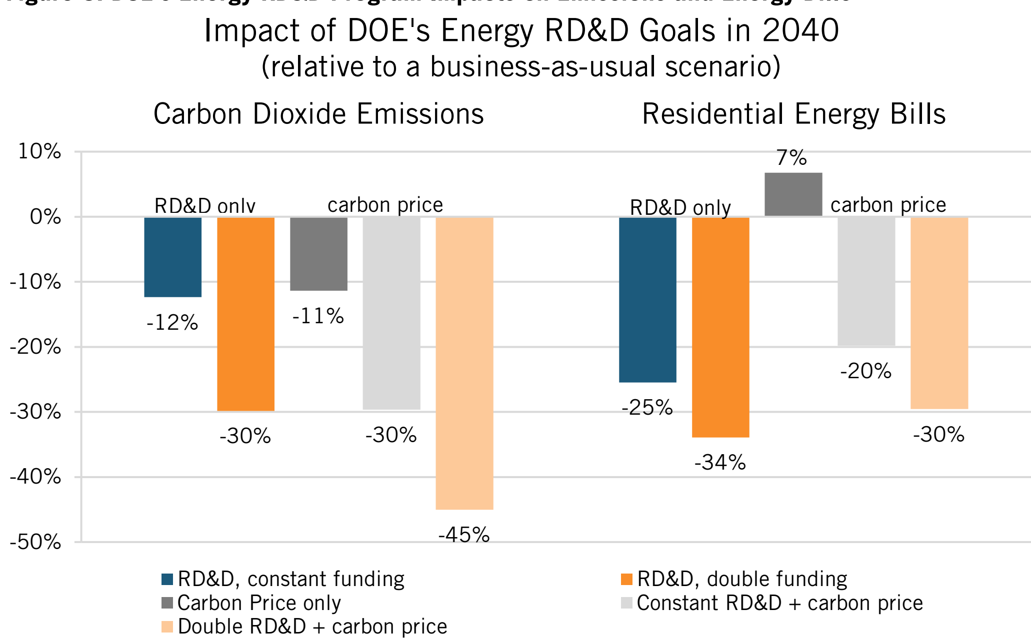
- Reducing the average energy use per square foot of commercial and residential buildings, saving consumers up to $100 billion annually in energy costs, and cutting carbon emissions by 450 million metric tons;[55]
- Reducing the cost of batteries for electric vehicles (EV) to $80/kWh, bringing the total cost of ownership in-line with that of conventional cars and trucks;[56]
- Lowering the cost of grid-scale energy storage technologies to $100/kWh, enabling greater penetration of renewable technologies such as solar PV and wind power;[57]
- Reducing the cost of carbon capture to under $30 per metric ton, which could result in up to 30 gigawatts of carbon capture technologies and more than 150 million metric tons of CO_2 sequestered by 2030;[58]

- Reducing fugitive emissions from natural gas systems by 40 to 45 percent, which would improve public safety, reduce greenhouse gas emissions, and ensure more natural gas makes its way from the producer to the end customer.[59]

If DOE could achieve all of its targets, the nation would gain significant benefits, including lower consumer energy bills and better health and environmental outcomes. DOE's 2017 *Quadrennial Energy Review* projected the potential benefits of its RD&D investments across five scenarios:[60]

- "Constant RD&D funding" based on the technology improvements DOE can achieve with constant funding;
- "Double RD&D funding" that leads to significantly more rapid innovation;
- "Carbon price" with no DOE RD&D spending, starting at $10 per metric ton of CO_2 and increasing at 5 percent annually; and
- Both RD&D scenarios in combination with a carbon price.

Figure 8: DOE's Energy RD&D Program Impacts on Emissions and Energy Bills



As Figure 8 shows, sustaining DOE's energy RD&D programs at current budget levels through 2040 would reduce carbon dioxide emissions by roughly the same amount (12 percent) as imposing a modest but rising carbon price—but it would also cut residential energy bills by 25 percent. Doubling funding for energy RD&D, which would allow for more ambitious technology targets, would reduce CO_2 emissions by 30 percent and energy bills by 34 percent. A carbon price, combined with energy RD&D, drives greater emissions reductions than either approach does on its own. The most aggressive scenario considered—doubling the energy RD&D budget and adding a carbon price—would cut carbon emissions by 45 percent. Yet, it is worth bearing in mind that, even under this scenario, the United States would still need to cut emissions by another 35 percent between 2040 and 2050 in order to hit the 80 percent target set by the Paris climate accords.

Box 6: Buildings and Appliances

Investments in DOE's Building Technologies Office (BTO) between 2010 and 2015 culminated in the successful commercialization of 27 products across a range of energy-related technologies, including energy-efficient water heaters, solid-state lighting, and energy-saving windows. For example, the advanced dual evaporator technologies for refrigerators—which performs up to 50 percent better than conventional single-cycle refrigeration systems—was developed with assistance from BTO and successfully commercialized by Whirlpool Corporation in 2013.[61] A retrospective assessment of BTO investments between 1976 and 2015 across three technology areas—heating, ventilation, and air conditioning (HVAC); water heating; and appliances—found that BTO investments have yielded between $6 billion and $22 billion in economic benefits, with a benefit-to-cost ratio of between 20 to 1 and 66 to 1.[62]

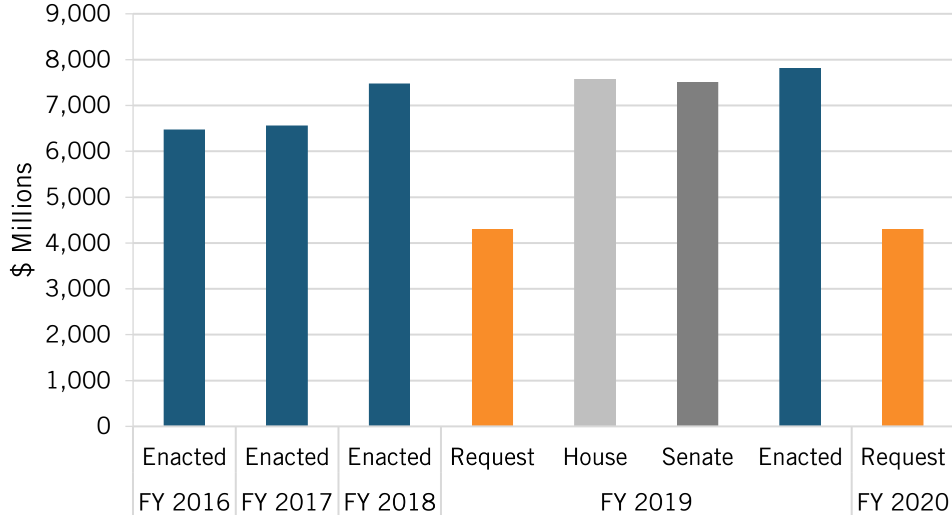
Because of its ability both to reduce carbon emissions and lower energy bills, expanding public investment in RD&D may be more palatable than carbon pricing to policymakers as they consider policy options to address climate change. But as DOE's analysis has found, RD&D can also "soften the blow" of carbon pricing and other regulatory options, opening up avenues of climate policies that would otherwise be prohibitively expensive or politically untenable.

Large majorities of voters across the political spectrum support more funding for research into clean energy. A December 2018 poll found that 88 percent of registered voters support funding more research into clean energy sources such as solar and wind power.[63] The higher levels called for by groups such as AEIC would allow DOE to achieve its current technology goals more quickly and enable new RD&D programs with more aggressive goals to hasten the next phase of the fight against climate change. The drastic cuts proposed by the Trump administration would jeopardize DOE's ability to meet its targets.

WHAT HAPPENS NEXT

The president's budget request is only the first step in the appropriations process, while Congress makes the final disposition of funds. During the last appropriations cycle, both the House and Senate firmly rejected the proposed budget cuts, instead providing a 14 percent boost to energy RD&D in FY 2018, and a more modest 5 percent increase in FY 2019.

Figure 9: Energy RD&D Programs in the Appropriations Process, FY 2016–FY 2020[64]



These outcomes over the last two budget cycles were enabled by the budget agreement in February 2018 that provided a two-year abeyance of the caps imposed under sequestration. The budget caps come back into effect for FY 2020 and FY 2021, which could set up DOE's programs for a sharp funding drop in FY 2020. The American Association for the Advancement of Science believes a more likely scenario is Congress will reach an agreement that avoids deep cuts to energy RD&D—though the prospect of future increases in energy RD&D funding is uncertain.[65]

CONCLUSION

DOE's clean energy RD&D portfolio plays an essential role in the U.S. energy innovation ecosystem, and has the potential to accelerate the clean energy transition while also lowering energy costs for U.S. businesses and consumers. The Trump administration's budget request would slash funding for these programs, slowing innovation and hampering U.S. competitiveness at a time when a number of indicators—including rising carbon emissions and declining clean energy patents—show the United States is significantly underinvesting in this field. Congress should reject the Trump budget proposal, elevate energy innovation as a national priority, and continue to expand federal funding for DOE's energy RD&D programs.

APPENDIX A: PRESIDENT TRUMP'S FY 2020 BUDGET REQUEST FOR DOE

Table 1: President Trump's FY 2020 Budget Request for DOE, in Millions

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 WH Request	Change
DOE Total Budget	$34,520	$35,685	$31,703	-11%
Defense	15,509	16,089	17,520	9%
Environmental Management	7,126	7,175	6,469	-10%
Basic Science Research	3,548	3,755	3,185	-15%
Other	769	749	387	-48%
DOE Energy RD&D Programs*	7,567	7,917	4,142	-48%
ARPA-E	353	366	-287	-178%
Electricity Delivery/CESER**	248	276	339	23%
Cybersecurity for Energy Delivery Systems***	76	90	75	-16%
Grid Modernization R&D	125	132	156	18%
Energy Efficiency & Renewable Energy*	2,322	2,379	343	-86%
Sustainable Transportation				
Vehicle Technologies	338	344	73	-79%
Bioenergy Technologies	222	226	40	-82%
Hydrogen & Fuel Cell Tech	115	120	44	-63%
Renewable Energy				
Solar Energy	242	247	67	-73%
Wind Energy	92	92	24	-74%
Water Power	105	105	45	-60%
Geothermal Technology	81	84	28	-67%
Energy Efficiency				
Advanced Manufacturing	305	320	81	-75%
Building Technologies	221	226	57	-75%
Use of Prior Year Balances			***-353***	
Fossil Energy R&D	727	740	562	-24%
CCUS and Advanced Power	481	486	387	-20%
Natural Gas Technologies	50	51	11	-79%
Unconventional Oil Tech	40	46	19	-59%
Other R&D	51	51	41	-20%
Nuclear Energy*	1,205	1,326	824	-38%
Reactor Concepts RD&D	237	324	215	-33%
Nuclear Energy Enabling Tech	159	153	98	-35%
Fuel Cycle R&D	260	264	90	-66%
Other R&D	13	13	0	-100%
Science	6,260	6,585	5,546	-16%
Basic Energy Sciences	2,090	2,166	1858	-14%
Fusion Energy Sciences	532	564	403	-29%
BER Bioenergy Research	90	100	100	--

* Program office totals include some non-RD&D functions.
** OE and CESER received an additional $13 million in supplemental hurricane funding in FY 2018, raising office totals to $261 million for FY 2018.

*** The budget proposes moving the energy delivery system testing and analysis laboratory within CEDS into the Infrastructure Security and Energy Restoration office. The remainder of cybersecurity research in CEDS would continue at FY 2019 levels.

Table 2: DOE's Technology Cost and Performance Targets[66]

Office	Program	Performance Goal	End Target	FY2019 Target
EERE	Vehicles	Batteries - Reduce the cost of batteries for Electric Vehicles (EVs).	$100/kWh by 2028	$185/kWh
EERE	Vehicles	Fuel economy - Improve Light Duty vehicle fuel economy (mpg).	48.6 mpg in 2030	42.5 mpg
EERE	Bioenergy	Algae - Increase algal biomass productivity.	25 g/m^2/day by 2025	15.9 g/m^2/day
EERE	Bioenergy	Decrease fuel selling price for the fast pyrolysis of biomass.	$3/gge by 2025	$3.84/gge
EERE	H2 & Fuel Cells	Improve the catalyst activity of Platinum Group Metal-free catalysts.	44 mA/cm^2 by 2025	29 mA/cm^2
EERE	H2 & Fuel Cells	Reduce the cost of hydrogen delivery and dispensing.	$5/kg by 2025	$12/kg
EERE	H2 & Fuel Cells	Identify advanced water-splitting materials and associated pathways.	11 materials by 2022	5 materials
EERE	Solar	CSP - Reduce the levelized cost of Concentrated Solar Power energy.	$50/MWh by 2030	$80/MWh
EERE	Solar	Reduce the system cost of solar + batteries w/ 4 hours of storage.	\$1.45/W_{DC}	\$1.65/W_{DC}
EERE	Solar	PV - Reduce nationwide average, unsubsidized cost of utility-scale solar PV.	$30/MWh by 2030	$55/MWh
EERE	Wind	Offshore - Reduce the cost of offshore wind energy.	$93/MWh by 2030	$157/MWh
EERE	Wind	Onshore - Reduce the average unsubsidized cost land-based wind energy.	$31/MWh by 2030	$50/MWh
EERE	Water	Dams - Reduce the cost of hydropower from non-powered dams.	$75/MWh by 2030	$94/MWh
EERE	Water	Marine & Hydrokinetic - Reduce the cost of energy from MHK technologies.	$270/MWh by 2030	$600/MWh
EERE	Water	Streams - Reduce the cost of energy from new stream developments.	$89/MWh by 2030	$112/MWh
EERE	Geothermal	Reduce the cost of energy from new hydrothermal and enhanced geothermal	$60/MWh by 2030	$217/MWh
EERE	Manufacturing	Improve manufacturing energy intensity relative to 2015 baseline.	17.5% by 2022	10%
EERE	Buildings	HVAC - Identify tech solutions for dehumidification with less energy use.	3 tech solns by 2021	1 tech soln
EERE	Buildings	Lighting - Increase power-conversion efficiency of amber light.	30% by 2025	15%
OE	Energy Storage	Energy Storage - Lower the cost of grid-scale (>1 MW) energy storage.	$100/kWh by2025	$225/kWh
OE	Transmission	Demonstrate technologies that improve transmission system monitoring.	--	--
OE	Distribution	Develop integrated distribution control architectures to improve resilience.	--	--
OE	Transformer	Develop standardized transformers with improved resilience and flexibility.	--	--
CESER	Cybersecurity	Develop new protective measures to reduce risks from cyber incidents.	--	--
FE	Natural Gas	Reduce fugitive methane emissions from natural gas infrastructure.	50% red by 2022	5%
FE	Oil	Improve unconventional oil resource recovery.	12% by 2022	11%
FE	Coal	Reduce the cost of carbon capture for new and existing coal power plants.	\$30/t CO_2 by 2030	--
FE	Coal	Improve the efficiency (heat rate) of existing coal power plants.	32.5% by 2022	31%
FE	Coal	Increase the efficiency (heat rate) of new coal power plants.	40% by 2023	38%

ENDNOTES

1. The federal budget does not provide a definition or establish a separate category for demonstration; it is encompassed within the definition of "development." However, many energy technologies must be demonstrated at full scale after they have been developed to the point of practical use at bench or pilot scale and before they can be widely deployed and integrated into the energy system. In this report, therefore, we use the term "RD&D" when referring to the overall federal energy innovation investment, but the term "R&D" when discussing specific appropriations that fall within the official budgetary definition of R&D, or when using data from particular statistical sources, such as *Science and Engineering Indicators*.
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ACKNOWLEDGMENTS

The author wishes to thank the David M. Hart and Rob Atkinson for providing input to this report. Any errors or omissions are the author's alone.

ABOUT THE AUTHOR

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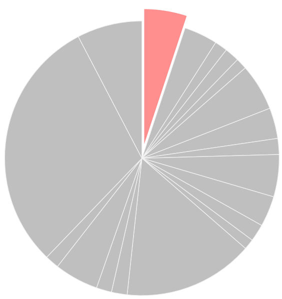
Federal Energy R&D: ARPA-E

BY COLIN CUNLIFF | APRIL 2019

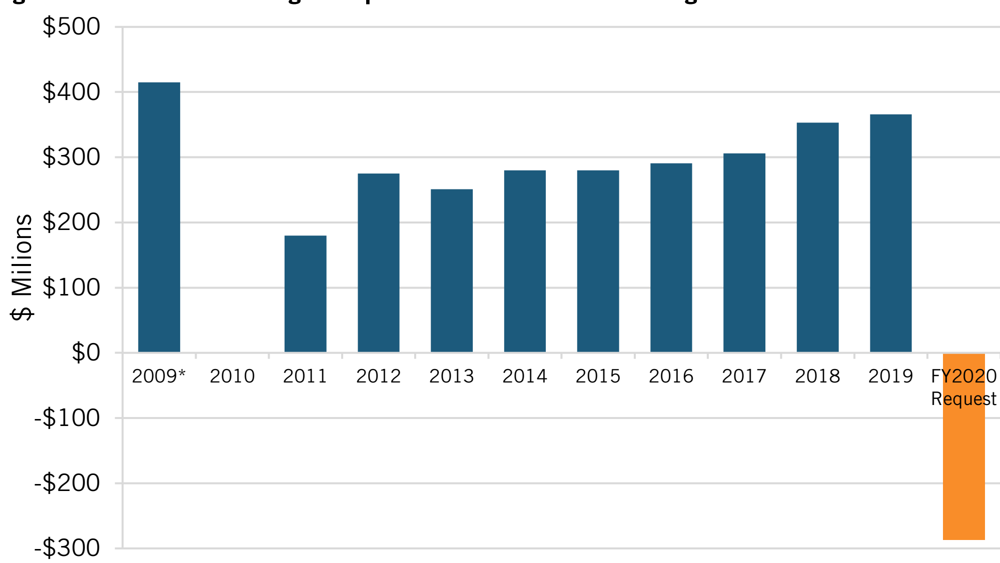
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



ARPA-E (pink)
Energy R&D (light grey)

Modeled after the highly successful Defense Advanced Research Projects Agency (DARPA), the Advanced Research Projects Agency-Energy (ARPA-E) advances high-potential, high-impact energy technologies that could radically improve U.S. economic prosperity, national security, and environmental well-being, but are too early for private-sector investment. Its grants help fund energy innovators who are developing technologies to solve critical cross-cutting, real-world problems in transportation, electricity, building, and other sectors.

Figure 1: The FY 2020 Budget Request Would Eliminate Funding for ARPA-E.[1]



What's At Risk

Created by Congress in 2007, and funded for the first time in 2009, ARPA-E is an important new institution that has proven to be a valuable and versatile catalyst of energy innovation.[2] Compared with traditional R&D programs, ARPA-E was designed to focus more on the potential impact of the research that it funds. To qualify for ARPA-E funding, each program must explain how its success will change the global energy landscape, identify the key barriers to making such a change, and lay out a set of milestones and metrics for assessing progress.

ARPA-E's high-risk/high-reward ventures are already yielding big returns. As of February 2018, 74 ARPA-E projects had attracted more than $2.6 billion in private-sector follow-on funding; 71 ARPA-E project teams had formed new companies to advance their technologies; and 109 ARPA-E projects had partnered with other government agencies for further development. Moreover, ARPA-E projects have generated 1,634 peer-reviewed journal articles, along with 248 new patents.[3] According to a recent ITIF analysis, on average, firms funded by ARPA-E raise more private capital than other clean-energy start-up firms.[4] The FY 2020 budget's proposed elimination of ARPA-E would therefore significantly undermine federal efforts to tackle urgent problems of energy supply, management, and use—and eliminate an important source of institutional innovation within DOE.

ARPA-E R&D Programs and Projects

ARPA-E funds are not bound by the technology-specific silos of DOE's applied-energy offices. Rather, ARPA-E's programs are developed by technical experts drawn from industry and academia who, during their three- or four-year terms as program managers, engage intensively with communities of researchers and innovators to create targeted, time-limited programs that seek to fill the "white space" of underexplored but potentially great ideas. In addition, ARPA-E holds open competitions every three years to bring to light promising ideas that might otherwise slip through the cracks between energy R&D programs.

ARPA-E currently funds 261 projects across 38 active programs, which are broadly organized into four areas: electricity generation, efficiency and emissions, transportation and storage, and grid and grid storage.[5] These projects provide a sense of ARPA-E's accomplishments:

- Primus Power, which sells zinc bromide flow batteries, was named one of the prestigious 2019 Global Cleantech 100 companies and has raised almost $100 million in equity investment. It recently upgraded its system deployed as part of a microgrid at Marine Corps Air Station Miramar and was reported to have some 7 megawatts of firm orders.[6]

- Foro Energy has developed a unique system for transmitting high-power laser light over long distances via fiber-optic cables for the purpose of ablating or welding materials. Potentially 10 times more economical than conventional hard-rock-drilling technologies, these "laser-assisted drill bits" could provide an effective way to gain access to the U.S. energy resources currently locked under hard-rock formations.[7]

- An ARPA-E-funded research team lead by Clemson University in South Carolina is developing resilient sorghum varieties that will be optimized for energy biomass production on land in the Southeast not suitable for food production.[8]

Key Elements of the FY 2020 Budget Proposal

ARPA-E would be completely eliminated. Additionally, the budget would rescind $287 million of previously appropriated funding, taking advantage of the fact that ARPA-E has been slow to spend funds appropriated by Congress for FY 2018 and FY 2019. The Government Accountability Office found that the Trump administration had deliberately and unlawfully withheld ARPA-E from spending its FY 2017 appropriation, and this pattern may have been repeated in the last two years.[9] The Natural Resources Defense Council (NRDC) found that, as of December 10, 2018—more than two months after the end of fiscal year 2018—ARPA-E had been unable to spend some $280 million (79 percent) of its $353 million FY 2018 research budget, and had not even begun to spend its FY 2019 RD&D budget.[10]

ENDNOTES

1. In 2009, ARPA-E received $15 million in regular appropriations and $400 million in one-time funding pursuant to the American Recovery and Reinvestment Act. The FY 2020 budget proposes eliminating ARPA-E and rescinding $287 million in previously-appropriated funding. Department of Energy, "FY 2020 Congressional Budget Request: Budget in Brief," (DOE CFO, March 2019), p 10, https://www.energy.gov/sites/prod/files/2019/03/f60/doe-fy2020-budget-in-brief.pdf.
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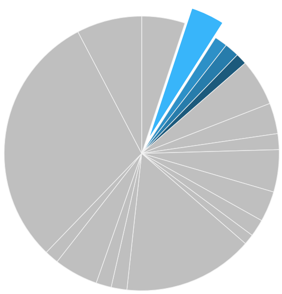
Federal Energy R&D: Solar Energy

BY COLIN CUNLIFF | APRIL 2019

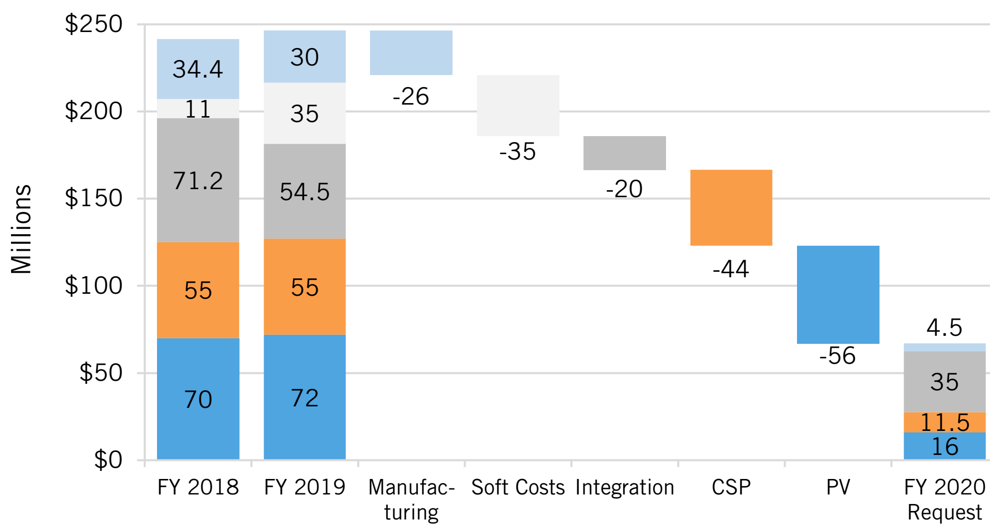
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



Solar (light blue)
Other Renewables
Energy R&D (light grey)

The Department of Energy's (DOE) Solar Energy Program embraces two complementary technologies: photovoltaics (PV), which convert light to electricity via semiconductors, and concentrating solar power (CSP), which converts light to heat that can then be stored and used to generate electricity. The program also works to integrate these electricity generation technologies more effectively into the transmission and distribution grid, and transfer DOE solar innovations into domestic manufacturing capabilities.[1]

Figure 1: The FY 2020 Budget Request Would Cut Solar Energy R&D by 73 Percent.[2]



What's At Risk

DOE's SunShot Initiative program has already achieved its 2020 goal of utility-scale solar PV power at six cents per kilowatt-hour ($0.06/kWh), making it a competitive source for electricity generation in areas with good solar resources and low PV penetration.[3] DOE should build on this success to reduce costs to the point solar PV becomes more competitive for utility, residential, and commercial systems as well—especially when factoring in the costs of integration. SunShot's 2030 goal for utility-scale solar PV is $0.03/kWh, which is 50 percent below today's utility-scale cost. Goals for commercial solar ($0.04/kWh) and residential solar ($0.05/kWh) are even more ambitious, requiring cost reductions of 40–70 percent of today's costs.[4] Achieving these goals would make solar one of the least-expensive sources of electricity generation, costing less than most fossil-fuel-powered sources, thereby contributing to energy affordability while reducing carbon emissions.[5]

The nine CSP systems operating in the United States today have demonstrated solar power's ability to provide 24-hour energy to the grid—although not yet at a competitive cost.[6] DOE's 2030 goal for baseload CSP power is $0.05/kWh, or 50 percent below the 2018 benchmark.[7] These targets are competitive with other dispatchable power generators and would enable greater overall penetration of solar electricity into the grid, while also enabling more reliable solar generation and increasing its value to the grid.

Solar Energy R&D Subprograms

R&D in the Solar Energy program is spread across five subprograms:[8]

- **Photovoltaics (PV)** funds research and development to enable improved PV performance, including advanced silicon processes, multijunction solar-cell efficiency, advanced materials science for cadmium-telluride solar cells, hybrid organic-inorganic perovskites, and impacts of outdoor soiling, temperature cycling, ultraviolet light, and humidity on PV performance.

- **Concentrating Solar Power (CSP)** focuses on component-level research and development in solar collection, receivers and heat-transfer fluids, power conversion, and thermal-energy storage, as well as integration of subcomponent technologies.

- **Systems Integration** coordinates with the DOE Grid Modernization Initiative to address key technical challenges related to the grid integration of solar power, including power variability, voltage regulation, frequency control, unintentional islanding, protection coordination, and two-way power flow.

- **Balance of Systems Soft-Cost Reduction** focuses on reducing non-hardware costs—including financing, customer acquisition, permitting, installation, labor, and inspection—which constitute over half the cost of total system prices for residential, commercial, and community PV systems.

- **Innovations in Manufacturing Competitiveness** funds the development and demonstration of innovative solar manufacturing technologies, and helps companies with promising solar technology survive the funding gaps that often emerge in the development cycle of new technologies.

Key Elements of the FY 2020 Budget Proposal[9]

- **Elimination of the Soft Costs subprogram**, including elimination of workforce training for veterans and other activities to address workforce gaps, as well as activities to reduce permitting, inspection, and interconnection costs and to improve access to low-cost financing. Elimination of this subprogram threatens to derail progress toward the 2020 and 2030 cost goals for residential and commercial solar, given that soft (non-hardware) costs constitute more than half of total system prices for residential, commercial, and community PV systems.

- **An 85-percent reduction in the Innovations in Manufacturing subprogram,** including a discontinuation of funding for the SunShot Incubator program, which provides early-stage assistance to small businesses commercializing innovative solar technologies. Funding to support scalable production methods, such as roll-to-roll manufacturing and solution processing, would also be discontinued.

- **A 79-percent reduction in the Concentrating Solar Power subprogram,** with no new funding to support solar thermal desalination, and reduced funding to support CSP R&D at the national labs on long-term thermal energy storage, new materials and manufacturing techniques, and autonomous solar field operation. Remaining activities would support energy storage and power cycle integration as part of the administration's crosscutting Advanced Energy Storage Initiative.

- **A 78-percent reduction in the Photovoltaic R&D subprogram**, including a discontinuation of funding for new PV materials and R&D to improve PV efficiency. The Regional Test Centers in Nevada, Vermont, and Florida, which provide facilities to study and validate the performance of PV technologies, would not be funded.

- **A 36-percent cut in the Systems Integration subprogram**, with decreased attention to power system planning and operation, grid sensing and communication integrity, data analytics, and integrating distributed solar systems with building loads and energy storage. Remaining funding would support developing lab and field test capabilities for power electronics-based PV, as well as the administration's crosscutting Advanced Energy Storage Initiative.

ENDNOTES

1. Department of Energy, "About the Solar Energy Technologies Office," https://www.energy.gov/eere/solar/about-solar-energy-technologies-office, accessed March 22, 2019.
2. The FY2020 budget for EERE would use $353 million in prior year (FY 2018 and FY 2019) balances to fund FY2020 programs. Thus the numbers shown in the figure underestimate the magnitude of cuts included in the proposed budget. Department of Energy, "FY 2020 Congressional Budget Request: Budget in Brief," (DOE CFO, March 2019), p 3, https://www.energy.gov/sites/prod/files/2019/03/f60/doe-fy2020-budget-in-brief.pdf; DOE, "FY 2020 Congressional Budget Justification" Volume 3 Part 2, 103 (DOE Chief Financial Officer DOE/CF-0153, April 2019), https://www.energy.gov/sites/prod/files/2019/04/f61/doe-fy2020-budget-volume-3-part-2_0.pdf.
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Technologies Office,” https://www.energy.gov/eere/solar/goals-solar-energy-technologies-office, accessed March 19, 2019;

5. For comparison, the levelized cost of electricity from a natural gas combined-cycle power plant was $0.042–0.078/kWh in 2017. Lazard, “Lazard’s Levelized Cost of Energy Analysis—Version 11.0,” (Lazard, November 2017), https://www.lazard.com/perspective/levelized-cost-of-energy-2017/.
6. National Renewable Energy Laboratory, “Concentrating Solar Power Projects in the United States,” https://solarpaces.nrel.gov/, project database accessed March 22, 2019. The NREL CSP Projects database lists 17 operational CSP systems, but we are counting multiple systems at the same site as a single project. For example, the Solar Electric Generating Station includes seven operational CSP systems in San Bernardino County, California that are counted here as a single system.
7. DOE, “Goals of the Solar Energy Technologies Office;” DOE, “FY 2020 Congressional Budget Justification,” Volume 3 Part 2, 101.
8. Summarized from DOE-SETO websites and Department of Energy, *FY 2019 Congressional Budget Request*, Volume 3 Part 2 (DOE/CF-0141, March 2018), 109-125.
9. DOE, FY 2020 Congressional Budget Justification Volume 3 Part 2, 101-114.

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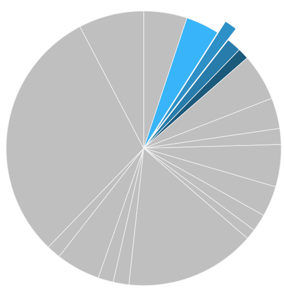
Federal Energy R&D: Wind Energy

BY COLIN CUNLIFF | APRIL 2019

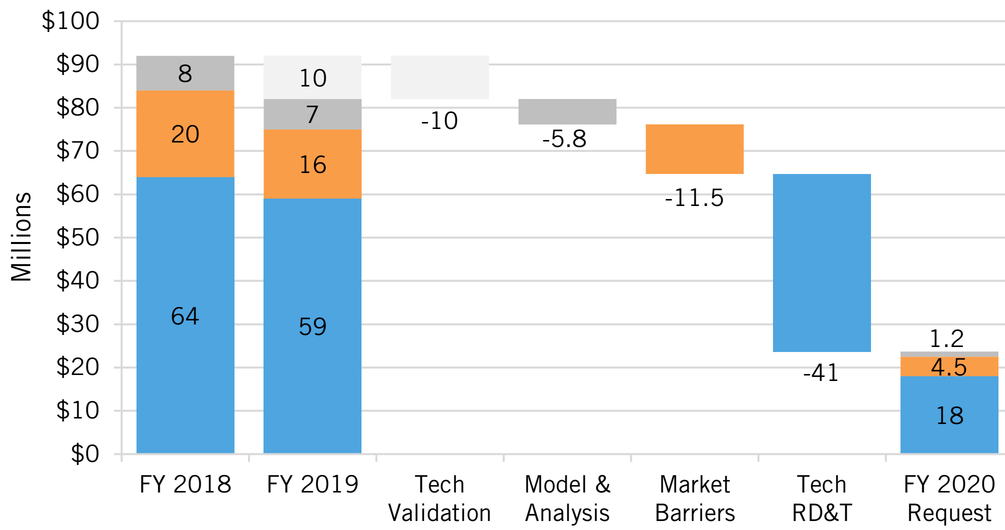
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



Wind (blue)
Other Renewables (blue)
Energy R&D (light grey)

The Department of Energy's (DOE) Wind Energy program targets innovations in onshore, offshore, and distributed wind power to capture the kinetic energy in wind and turn it into electricity via spinning generators. The program also works to integrate wind generation more effectively into the bulk power system to enable wind farms to provide more reliable power output and essential reliability services to the grid.[1]

Figure 1: The FY 2020 Budget Request Would Cut Wind Energy R&D by 74 Percent.[2]



What's At Risk

DOE's Wind Energy program has already achieved substantial cost reductions and technology improvements that have enabled the rapid expansion of land-based wind power. The cost of energy from land-based wind power has decreased from more than 55 cents per kilowatt-hour ($0.55/kWh) in 1980 to a national average of $0.046/kWh in 2015, thus enabling the expansion of wind power to 41 states.[3] DOE should build on this success to improve performance and reduce costs much further until unsubsidized wind power becomes competitive across more parts of the country. DOE's "Wind Vision" report provides a path to reducing the cost of energy from unsubsidized land-based wind to $0.023/kWh and achieving a 50 percent reduction in the cost of energy from offshore and distributed wind by 2030. Achieving these goals could enable up to 200 gigawatts (GW) of total wind capacity by 2030, thereby contributing to energy affordability and security while also reducing carbon emissions.[4]

The nascent offshore wind industry is beginning to take off, with 25,500 megawatts (MW) of new offshore wind capacity in development, of which 2,000 MW are expected to be operational by 2023.[5] Offshore wind could present a low-carbon energy alternative for the 28 coastal and Great Lake states, although additional cost reductions will be needed to make it cost competitive with other sources of electricity—as it already is in parts of Europe. Validation and demonstration of new offshore wind technologies will also provide investors with greater confidence in the growing array of energy projects in U.S. waters.[6]

Wind Energy R&D Subprograms

R&D in the Wind Energy program is divided into four subprograms:[7]

- **Technology Research, Development, & Testing (RD&T) and Resource Characterization** focuses on turbine technology innovations; systems-level optimization of multi-turbine wind power plants; soft costs for distributed wind; and other innovations to reduce the cost and enhance the value of wind energy. The subprogram also manages wind-specific test facilities that enable validation and testing of public- and private- R&D.

- **Technology Validation and Market Transformation** conducts high-risk testing and validation of new technologies, including innovative offshore wind pilot projects, and collect and produces public performance and environmental data sets.

- **Mitigate Market Barriers R&D** identifies research needs evaluates technology solutions to address wind-turbine radar interference, wildlife impacts, and community impacts; supports STEM and workforce programs; and funds R&D to develop and refine the ability of wind turbines to provide frequency, voltage, and ramping support to the grid.

- **Modeling and Analysis** identifies and evaluates opportunities to reduce the cost and improve the value of land and offshore wind technologies in order to inform and prioritize R&D activities.

Key Elements of the FY 2020 Budget Proposal[8]

- **Elimination of the Technology Validation and Market Transformation subprogram**, which has supported demonstration of first-of-a-kind offshore wind technologies at two sites: the first freshwater offshore wind project in North America, the Lake Erie Icebreaker Project off the coast of Cleveland, Ohio; and a floating offshore wind farm in the deep waters off the coast of Main, where fixed-bottom installations are not feasible.

- **A 69-percent reduction in the Technology RD&T and Resource Characterization subprogram**, which houses the Atmosphere to Electrons (A2e) initiative and the Big Adaptive Rotor (BAR) initiative, and provides support to Sandia's Scaled Wind Farm Technology (SWiFT) / National Rotor Testbed (NRT) facility in Texas and National Renewable Energy Laboratory's National

Wind Technology Center (NWTC) in Colorado, which hosts testing facilities for industry and academia to test and validate their innovations. The proposal would reduce funding in atmospheric wind science, wind plant reliability and optimization, tall wind, advanced manufacturing, and materials for wind energy, and includes no new competitive funding opportunities.

- **An 83-percent reduction to the Modeling and Analysis subprogram**, with no new funding for a project to identify the turbine, substructure, and balance-of-plant R&D pathways to achieve deep cost reductions for floating offshore wind systems; reduced funding for systems engineering and other analysis to identify opportunities to reduce the cost of wind and enhance wind's value to the electricity system, e.g., through the provision of essential reliability services; and no new competitive funding opportunities.
- **A 72-percent reduction in the Mitigate Market Barriers subprogram,** including reduced funding for workforce development programs; research to address regulatory restrictions associated with radar interference and environmental impacts of offshore wind; research to enhance the ability of wind to provide essential reliability services, including inertia, frequency response, and voltage control; and research into dynamic line rating forecasting for transmission lines.

ENDNOTES

1. DOE, "FY 2020 Congressional Budget Justification," Volume 3 Part 2, 115-132, (DOE/CF-0153, April 2019), https://www.energy.gov/sites/prod/files/2019/04/f61/doe-fy2020-budget-volume-3-part-2_0.pdf.
2. The FY2020 budget for EERE would use $353 million in prior year (FY 2018 and FY 2019) balances to fund FY2020 programs. Thus the numbers shown in the figure underestimate the magnitude of cuts included in the proposed budget. Department of Energy, "FY 2020 Congressional Budget Request: Budget in Brief," (DOE CFO, March 2019), p 3, https://www.energy.gov/sites/prod/files/2019/03/f60/doe-fy2020-budget-in-brief.pdf; DOE, "FY 2020 Congressional Budget Justification" Volume 3 Part 2, 117.
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4. Katherine Dykes, et al., "Enabling the SMART Wind Power Plant of the Future Through Science-Based Innovation" (Washington, D.C.: DOE NREL, August 2017) https://www.nrel.gov/docs/fy17osti/68123.pdf; DOE, "Congressional Budget Justification," Volume 3 Part 2, 115.
5. Potential capacity includes installed projects, projects under construction, projects moving through permitting and offtake processes, projects with site control, the Bureau of Ocean Energy Management's unleased wind energy areas, and unsolicited lease applications submitted by developers. DOE, "2017 Offshore Wind Technologies Market Update Executive Summary" 5 (Washington, D.C.: DOE NREL, September 2018), https://www.energy.gov/sites/prod/files/2018/10/f56/exec-summary-71709_V4.-jf3.pdf.

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7. DOE, "FY 2020 Congressional Budget Justification," Volume 3 Part 2, 115-132.
8. Ibid.

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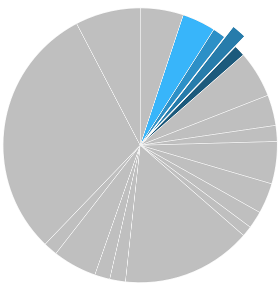


Water (blue)
Other Renewables (blue)
Energy R&D (light grey)

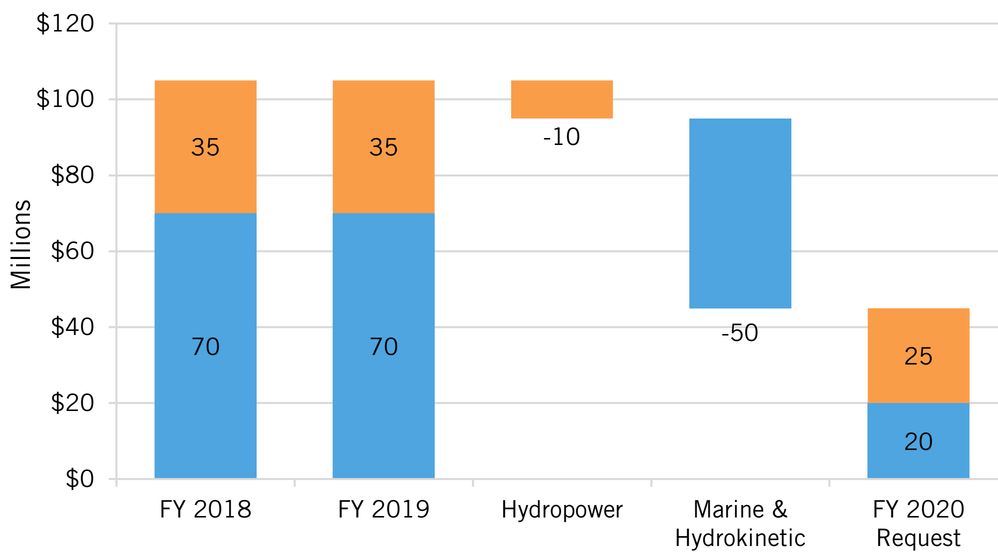
Federal Energy R&D: Water Power

BY COLIN CUNLIFF | APRIL 2019

This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.

The Department of Energy's (DOE) Water Power program supports research and development (R&D) of two types of technologies: conventional hydropower (including pumped storage), and marine and hydrokinetic (MHK) energy. Conventional hydropower uses a dam or other structure to convert the kinetic energy of flowing water into electricity, while MHK technologies convert the energy of waves, tides, and currents into electricity.[1]

Figure 1: The FY 2020 Budget Request Would Cut Water Power R&D by 57 Percent.[2]



What's At Risk

Hydropower is the largest source of renewable energy, providing 7 percent of the nation's electricity (and 19 percent of its carbon-free electricity) in 2018.[3] However, installed capacity of conventional hydropower and pumped storage hydropower has stalled at about 100 gigawatts (GW), and innovation is needed to jumpstart growth in hydropower. DOE's 2016 "Hydropower Vision" report identified up to 50 GW of new hydropower capacity that could be gained from upgrading and modernizing the existing fleet, installing generation on non-powered dams, and developing new, small hydropower and pumped-storage technologies. Near-term growth of hydropower generation through 2030 is estimated at 9.4 GW, while approximately 16.2 GW in new pumped-storage hydropower could also become available. New technologies and system-design concepts are needed to reduce costs and improve efficiency in order to realize this potential.[4]

National resource assessments have found 1.25–1.85 terawatt-hours per year (TWh/yr) of untapped, technically extractable MHK potential, or the equivalent of 30 percent of the total electricity generated in the United States.[5] MHK technologies are at an early stage of development due to the fundamental scientific and engineering challenges of generating power from complex low-velocity/high-density dynamics in a corrosive ocean environment. Although MHK technologies could potentially provide a low-carbon energy alternative for the 28 coastal and Great Lake states, additional cost reductions are needed to make them cost competitive with other sources of electricity.

Additionally, marine energy can provide new capabilities, such as onboard energy generation and remote recharging, in areas far from land-based power grids. In April 2019, DOE released a new report "Powering the Blue Economy" that identifies non-grid applications and opportunities for marine renewable energy to tap into new markets and provide new energy services.[6] However, the proposed budget cuts threaten to stall the progress currently being made to extract significant energy value from this rich national resource.

Water Power R&D Subprograms

R&D in the Water Energy program is spread across two subprograms:[7]

- **Hydropower R&D** seeks to reduce the site-specific costs of construction, powerhouse design/installation, and environmental mitigation of new hydropower at non-powered dams; develop turbine designs that generate more power at given water flows or increase operational ranges with reduced impacts for existing hydropower facilities; optimize modes of operation for grid stabilization; and develop novel closed-loop pumped-storage designs that can be deployed at a wider range of sites.

- **Marine and Hydrokinetic (MHK) Technologies** focuses on researching controls to maximize power production over a range of ocean conditions; improving and validating modeling tools and methodologies to optimize device and array performance and reliability across operational and extreme conditions; and investigating new approaches to safe and cost-efficient installation, grid integration, operations, maintenance, and decommissioning of MHK projects. MHK is currently developing an open-water wave-energy test facility—to be completed in 2021—that will allow testing and validation of industry-developed MHK energy-conversion components and systems.[8] MHK is also exploring the ability of marine energy to provide non-grid energy services in areas where access to an electric grid is limited.[9]

Key Elements of the FY 2020 Budget Proposal[10]

- **A 72-percent reduction in the MHK Technologies subprogram**, including reduced funding to test and validate performance of wave devices at the PacWave test facility, as well as elimination of funding for advanced materials, MHK device components, system design and validation, and infrastructure upgrades at the National Marine Renewable Energy Centers.

- **A 29-percent reduction in the Hydropower Technologies subprogram**, including reduced R&D funding for advanced manufacturing techniques for modular hydropower and elimination of incentives for deployment of hydropower at existing non-powered dams would be eliminated. Increased funding for pumped-storage hydropower R&D in support of the Advanced Energy Storage Initiative would offset these cuts.

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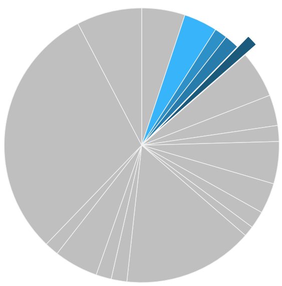
Federal Energy R&D: Geothermal Technologies

BY COLIN CUNLIFF | APRIL 2019

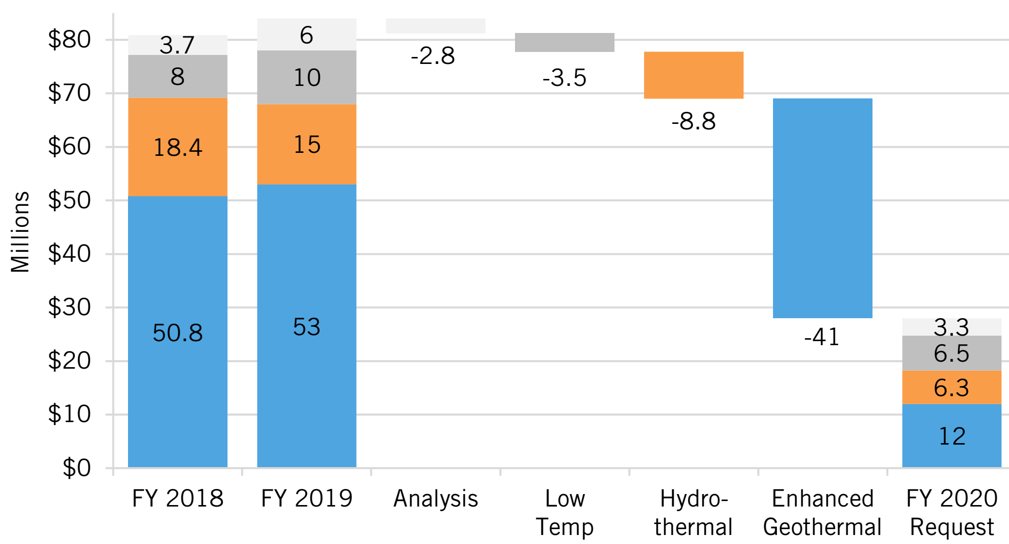
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



Geothermal (blue)
Other Renewables (blue)
Energy R&D (light grey)

Geothermal technologies use heat from the earth, either directly for such applications as heating and cooling, or to generate electricity. The Geothermal Technologies program supports research and development of two main types of geothermal technologies: hydrothermal and Enhanced Geothermal Systems (EGS). Hydrothermal resources exist naturally in areas where there is sufficient temperature and permeability in the subsurface for the flow of fluids to generate electricity. EGS, on the other hand, requires rock stimulation for permeability enhancement and fluid injection to allow commercial-scale fluid flow that can be used for electricity generation.[1]

Figure 1: The FY 2020 budget request would cut geothermal R&D by 67 percent.[2]



What's At Risk

In addition to the current U.S. installed capacity of geothermal energy of over 3.7 gigawatts (GW), there is a vast source of untapped energy just waiting to be realized: an estimated 30 GW of hydrothermal plus more than 100 GW of geothermal energy through EGS.[3] The geothermal industry operates in a harsh subsurface environment in which unique technical and operational challenges must be overcome to realize this potential. Foremost among these challenges is the resources essentially being "out of sight" at a depth of anywhere from two to five kilometers, thus requiring new exploration technologies and tools to reduce the near-term cost and risk of development. DOE has set an ambitious goal of reducing the cost of electricity from newly developed geothermal systems from 22 cents per kilowatt-hour ($0.22/kWh) in 2017 to $0.06/kWh by 2030.[4]

In addition, the United States has abundant low-temperature geothermal resources below 300 °F (150 °C), with potential applications for district heating and cooling, industrial process heating, and underground thermal energy storage. A recent U.S. Geological Survey assessment identified 46.5 GW thermal (GWth) of renewable heat could be extracted from geothermal resources below 200 F (90 C).[5]

But realizing the enormous potential of America's domestic low-carbon geothermal resources requires R&D to harness these resources more effectively, develop improved methods to stimulate new resources, and characterize and model subsurface stress and other reservoir properties. DOE's Geothermal Technologies Office is currently preparing the *GeoVision Study*, to be released in early 2019, to identify gaps in our understanding of the potential of geothermal resources and to inform DOE's R&D priorities as it seeks to reduce costs and increase access to geothermal resources.[6] Reductions in R&D funding threaten DOE's ability to take advantage of the most promising opportunities to advance geothermal technologies.

Geothermal Technologies R&D Subprograms

Geothermal R&D is divided among four subprograms:[7]

- **Enhanced Geothermal Systems (EGS)** explores materials and technologies to produce energy from man-made reservoirs that are otherwise not economical due to lack of water and/or permeability. Major initiatives include the EGS Collab, a small-scale field site in South Dakota for reservoir model prediction and validation, and the Frontier Observatory for Research in Geothermal Energy (FORGE) site in Utah, a facility where industry and government researchers can test and validate innovative EGS technologies in a deep rock environment.[8]

- **Hydrothermal R&D** focuses on technologies necessary to find and access "blind" conventional hydrothermal resources—geothermal resources that require little-to-no stimulation to improve permeability and fluid flow but without clear surface expressions—by targeting innovative approaches to microhole drilling applications, self-healing cements, and subsurface imaging.

- **Low-Temperature and Coproduced Resources** targets RD&D on technologies applicable to geothermal resources below a temperature of 300 °F (150 °C), including: direct use of thermal resources for process and space-heating applications; hybrid power designs that can be codeveloped with existing well-field infrastructures; and geothermal-enabling technologies, including thermal desalination processes and thermal energy storage.

- **Systems Analysis** focuses on identifying and addressing barriers to geothermal adoption, as well as validating and assessing technical progress to inform the direction and prioritization of the portfolio.

Key Elements of the FY 2020 Budget Proposal

- **A 77-percent decrease in the EGS subprogram**, including a $25 million cut to FORGE, as well as the use of previously-appropriated funding to conduct FY 2020 activities; no new funding for the EGS Collab; no new funding for additive manufacturing efforts at ORNL that would facilitate low-cost drilling; no new funding to support the Efficient Drilling for Geothermal Energy (EDGE) program; and no new funding opportunities / open laboratory calls to conduct high-impact EGS R&D. The proposal includes a new $6.7 million FORGE Wells of Opportunity activity to fund EGS stimulation R&D at available unused geothermal wells prior to testing at FORGE.

- **A 58-percent reduction in the Hydrothermal subprogram**, including a reduction in subsurface R&D to develop technologies to characterize and monitor subsurface stress; no new funding to support the Efficient Drilling for Geothermal Energy (EDGE) program; and no new funding opportunities / open laboratory calls to conduct high-impact hydrothermal R&D.

- **A 35-percent reduction in the Low Temperature subprogram,** including no new funding opportunities / open laboratory calls in novel low-temperature geothermal R&D and no new funding on critical mineral recovery from geothermal brines. The proposal would pivot R&D activities to focus on subsurface thermal energy storage as part of the administration's crosscutting Advanced Energy Storage Initiative.

- **A 46-percent decrease in the Systems Analysis subprogram**, including no new funding opportunities / open laboratory calls in geothermal systems analysis, and a new activity to identify non-technical barriers in geothermal market penetration.

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"includes both hydrothermal and Enhanced Geothermal Systems." However, the Fiscal Year 2020 Congressional Budget Justification states the goal of $0.06/kWh by 2050 "from newly developed enhanced geothermal systems" and also includes a separate goal of $0.09/kWh by 2022 "from currently undiscovered hydrothermal resources." The goals in the FY 2020 Congressional Budget Justification appear to reflect a reduction in ambition. DOE, "Fiscal Year 2017 Annual Performance Report / Fiscal Year 2019 Annual Performance Plan," 82 (DOE/CF-0147) https://www.energy.gov/sites/prod/files/2018/11/f57/fy-2017-doe-annual-performance-report-fy-2019-annual-performance-plan.pdf; DOE, "FY 2020 Congressional Budget Justification" Volume 3 Part 2, 153-157.

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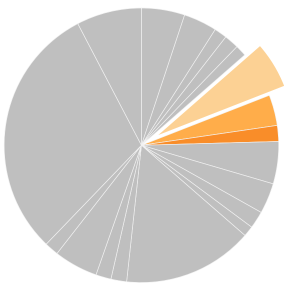
Federal Energy R&D: Vehicle Technologies

BY COLIN CUNLIFF | APRIL 2019

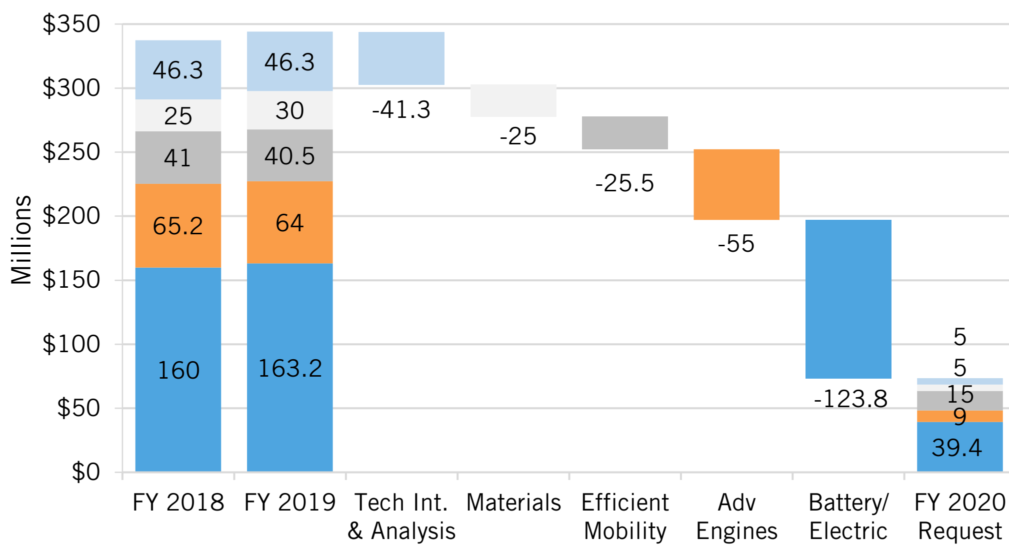
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



Vehicles (light orange)
Other Transportation (orange)
Energy R&D (light grey)

The transportation sector accounts for 70 percent of petroleum use and 34 percent of all carbon pollution, surpassing the power sector as the top source of U.S. greenhouse gas emissions in 2016.[1] The average U.S. household spends 16 percent of its total family expenditures on transportation, making it the most expensive spending category after housing.[2] With nearly 20 percent of U.S. petroleum consumption coming from imports, U.S. consumers send more than $15 billion per month overseas for crude oil.[3] By investing in R&D to use conventional fuels more efficiently and develop domestically produced alternative-vehicle technologies, the Vehicle Technologies Office (VTO) works to keep prices low for consumers, improve national energy security, and enhance environmental performance.[4]

Figure 1: The FY 2020 Budget Request Would Cut Vehicle Technologies R&D by 79 Percent.[5]



What's At Risk

The Vehicle Technologies office has established technology cost and performance targets to help meet national imperatives in energy security, environmental stewardship, and economic growth. Reaching these goals will require new technologies and cost reductions in batteries, efficient engines, fast-charging, lightweight materials, and other enabling technologies, as well as systems-level innovations in automated and connected vehicles and integration into electricity systems.

For electric vehicles (EVs), the office has established targets of reducing the cost of EV batteries by more than half, to $100/kWh, increasing the range to 300 miles, and decreasing charge time to 15 minutes or less by 2028. But new battery chemistries will be needed for the department to reach its cost targets and for electric vehicles to achieve their full potential.[6] Reductions in battery and electrification R&D funding threaten to delay progress toward these targets.

For conventional internal combustion engine vehicles, the office is working to develop the next generation of engines and fuels capable of improving passenger-vehicle fuel economy by 35 percent by 2030. The SuperTruck II research activity has set an ambitious target of doubling the freight-hauling efficiency of heavy-duty Class 8 long-haul trucks by 2020.[7] Long-haul trucking is a key "hard-to-decarbonize" transportation subsector not amenable to electrification using the same lithium-ion (Li-ion) batteries used in light-duty electric vehicles, and improving efficiency is one of the few good near-term options for lowering energy costs and reducing carbon emissions from this sector.[8] Reduced funding for these programs threaten to stall DOE's efforts to improve vehicle efficiency and save energy costs for consumers.

Vehicle Technologies R&D Subprograms

R&D in the Vehicle Technologies program is distributed across six subprograms:[9]

- **Battery and Electrification Technologies** explores new battery chemistry and cell technology to reduce the cost of EV batteries; supports work on EV integration with the electric grid; conducts R&D to improve electric drivetrains; and explores fast charging technologies.
- **Energy Efficient Mobility Systems (EEMS)** applies complex modeling and simulation to explore the energy impact of emerging disruptive technologies such as connected and autonomous vehicles, information-based mobility-as-a-service platforms, and advanced powertrain technologies in order to identify opportunities to improve efficiency.
- **Advanced Engine & Fuel Technologies R&D** works to develop advanced combustion engines and co-optimize fuels and engines to improve fuel economy.
- **Materials Technology** supports vehicle lightweighting and improved propulsion (powertrain) efficiency through materials R&D.
- **Technology Integration** supports cooperative agreements with Clean Cities coalitions, maintains the Alternative Fuels Data Center and the annual Fuel Economy Guide, conducts transportation data and systems research, and supports the collegiate advanced vehicle technology competitions and other workforce development programs.
- **Analysis** provides technology, economic, and interdisciplinary analyses to inform and prioritize the Vehicle Technologies research portfolio.

Key Elements of the FY 2020 Budget Proposal

- **A 76-percent reduction of the Battery and Electrification Technologies subprogram,** including the elimination of battery-safety and thermal-performance research; no new funding for battery development work through the Advanced Battery Consortium; reduced funding for extreme fast charging R&D; reduced funding for battery materials and battery cells R&D; and no new funding for competitively awarded, cost-shared electrification projects.

- **Elimination of SuperTruck II activities,** a cross-cutting activity which aims to improve freight-hauling efficiency of heavy-duty Class 8 long-haul trucks. These trucks haul 80 percent of goods in the United States and consume about 28 billion gallons of fuel per year, accounting for 22 percent of total transportation energy usage. Achieving the SuperTruck II targets would save truck operators nearly $20 billion in fuel expenditures, while also reducing carbon dioxide emissions by 128 million metric tons.[10]

- **An 86-percent reduction of Advanced Engine & Fuel Technologies R&D,** including the elimination of research on spark-ignited engines; and reduced funding for medium- and heavy-duty engine technologies, predictive modeling of engine combustion, pollution control technologies, the co-optimization of engines and fuels (Co-Optima), and natural gas engine technologies.

- **A 63-percent reduction in Energy Efficient Mobility Systems,** including the reduced funding for the Systems and Modeling for Accelerated Research in Transportation (SMART) National Laboratory Consortium, as well as the high performance computing-enabled data analytics work to apply machine learning and data science tools to improve vehicle and transportation efficiency.

- **An 83-percent reduction in Materials Technology R&D**, including the elimination of research on composite lightweight materials, solid phase processing techniques for lightweight metal alloys, and cooperative public-private partnerships through the LightMAT Consortium to accelerate the discovery of advanced materials. Research in propulsion materials technologies, including powertrain weight reduction technologies, would be significantly reduced.

- **An 89-percent reduction in Technology Integration and Analysis**, including no new funding for technical assistance and other partnership activities through the Clean cities program; minimal support to meet statutory requirements for reporting on alternative fuel vehicles, new model year fuel economy, and other public information programs; reductions in the EcoCAR Mobility Challenge, a collegiate advanced vehicle technology competition; and reductions in analysis to inform and prioritize VTO technology investments and research portfolio planning.

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Federal Energy R&D: Bioenergy Technologies

BY COLIN CUNLIFF | APRIL 2019

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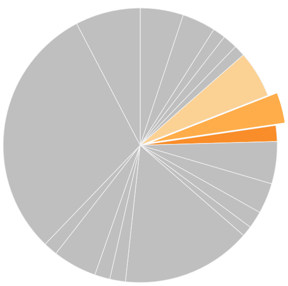
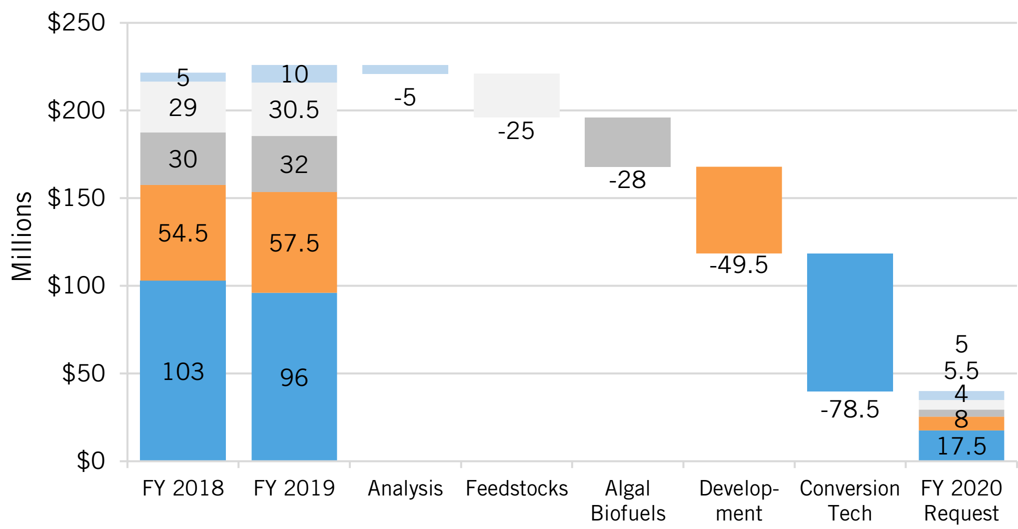


Bioenergy (orange)
Other Transportation (orange)
Energy R&D (light grey)

The Department of Energy's (DOE) Bioenergy Technologies Program (BETO) focuses on R&D to develop sustainable bioenergy technologies capable of producing price-competitive biofuels from nonfood sources of biomass such as wastes and agricultural residues, and energy crops like switchgrass and algae. The program's primary focus is on R&D to produce "drop-in" biofuels that are compatible with existing fueling infrastructure and vehicles across a range of transportation modes, including renewable gasoline, diesel, and jet fuels.[1]

Figure 1: The FY 2020 Budget Request Would Cut Bioenergy technologies R&D by 82 Percent[2]



What's At Risk

The United States has the resource potential to sustainably produce 1 billion dry tons of nonfood biomass resources by 2030 without disrupting agricultural markets for food and animal feed.[3] These resources could produce approximately 50 billion gallons of biofuels (25 percent of U.S. transportation fuels), 50 billion pounds of high-value chemicals and products, and 75 billion kWh of electricity (enough to power 7 million homes).[4] Algal biomass is an important kind of biomass due to its ability to grow quickly, use waste resources, and produce fuel precursors. Algal biofuels could potentially contribute up to 5 billion gallons per year—about 25 percent of the current jet-fuel market—by 2030.[5] And a number of bioenergy pathways, combined with carbon sequestration technologies, offer the potential to permanently remove carbon dioxide from the atmosphere and, resulting in net-negative emissions.[6]

Each of the bioenergy production and conversion targets within BETO was chosen to create new technology options that are more efficient than, and at least as affordable as, conventional technology. Achieving these targets will both improve transportation-energy affordability and take the United States one step closer to reaching its national goals in energy security, economic growth, and environmental stewardship. However, reductions in DOE R&D funding threaten to delay or even derail this progress.

Bioenergy Technologies R&D Subprograms

R&D in the Bioenergy program is distributed across these five subprograms:[7]

- **Feedstock Supply and Logistics** develops and improves strategies, technologies, and systems to provide consistent quality feedstock to biorefineries, while focusing on supply and logistics challenges to support further development of advanced biofuels. The Feedstock subprogram funds the Biomass Feedstock National User Facility at Idaho National Laboratory (INL), as well as the Feedstock Conversion Interface Consortium (FCIC), a consortium of eight national laboratories focused on feedstock handling, preprocessing, and conversion opportunities to reduce biofuel selling price.

- **Advanced Algal Systems** supports R&D of algal-biomass production and logistics systems, with a focus on improving capabilities to predict, breed, and select the best-performing algal strains, harvest algae at high-throughputs, and extract and convert algal biomass components into fuels.

- **Conversion Technologies** R&D focuses on converting biomass feedstocks into "drop-in" transportation fuels and co-produced bioproducts and explores both biological and thermochemical conversion pathways.

- **Advanced Development and Optimization (ADO)** collaborates with the Vehicle Technologies program on the Co-Optimization of Fuels & Engines (Co-Optima) initiative to develop biofuels and engines that are co-optimized to enable higher efficiency and performance.

- **Strategic Analysis and Cross-cutting Sustainability** provides quantitative analysis to inform BETO decisions regarding the future direction and scope of its R&D portfolio.

Key Elements of the FY 2020 Budget Proposal

- **An 86-percent reduction in the Advanced Development and Optimization R&D**, including discontinuation of all demonstration-scale biorefinery projects, as well as a discontinuation of research and testing of wood heaters, renewable energy production from urban and suburban wastes, and co-processing of biofuel intermediates in petroleum refineries. Funding for Co-Optimization of Fuels and Engines (Co-Optima) and systems R&D would be greatly reduced.

- **An 88-percent reduction in Advanced Algal Systems**, including a discontinuation of funding to capture CO_2 directly from the atmosphere, and substantial reductions in funding for algae research at DOE national labs such as the Development of Integrated Screening, Cultivar Optimization, and Validation Research (DISCOVR), a consortium of four national laboratories that focuses on increasing algal productivity and resilience.

- **An 82-percent reduction in Conversion Technologies R&D,** including substantial funding reductions for the three national lab consortia: the Agile BioFoundry, the Chemical Catalysis for Bioenergy (ChemCatBio) consortium, and the Bioprocessing Separations consortium. Funding for the research, development and testing of bio-derived products, automation systems for bioreactors, lignin valorization, and conversion of wet wastes to liquid fuels and renewable natural gas would also be reduced, and no funding would be provided for competitive solicitations for research with industry and academia.

- **A 78-percent reduction in Feedstock Supply and Logistics R&D,** including the elimination of funding for facility upgrades at the INL Biomass Feedstock National User Facility and no new competitive funding opportunities for biomass feedstock research. Funding for the FCIC and other national lab research to improve feedstock handling, preprocessing, and conversion, as well as harvest logistics and biomass densification, would be greatly reduced.

- **A 45-percent reduction in Strategic Analysis and Crosscutting Sustainability R&D**, including the elimination of funding for bioenergy sustainability research that addresses knowledge gaps related to food security, air, land, and water resources.

ENDNOTES

1. DOE, "FY 2020 Congressional Budget Justification" Volume 3 Part 2, 51 (DOE Chief Financial Officer DOE/CF-0153, April 2019), https://www.energy.gov/sites/prod/files/2019/04/f61/doe-fy2020-budget-volume-3-part-2_0.pdf.
2. The FY2020 budget for EERE would use $353 million in prior year (FY 2018 and FY 2019) balances to fund FY2020 programs. Thus the numbers shown in the figure underestimate the magnitude of cuts included in the proposed budget. Department of Energy, "FY 2020 Congressional Budget Request: Budget in Brief," (DOE CFO, March 2019), p 3, https://www.energy.gov/sites/prod/files/2019/03/f60/doe-fy2020-budget-in-brief.pdf; DOE, "FY 2020 Congressional Budget Justification" Volume 3 Part 2, 54.
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5. Ryan Davis, et al., "Renewable Diesel from Algal Lipids: An Integrated Baseline for Cost, Emissions, and Resource Potential from a Harmonized Model," Argonne National Laboratory, ANL/ESDA/12-4 (2012), http://greet.es.anl.gov/publication-algae-harmonization-2012.

6. Daniel L. Sanchez et al., "Chapter 5: Hybrid Biological and Engineered Solutions," in *Building a New Carbon Economy: An Innovation Plan* (Carbon180 and the New Carbon Economy Consortium) https://carbon180.org/s/ccr02innovationplanFNL.pdf; and Colin Cunliff, "An Innovation Agenda for Deep Decarbonization: Bridging Gaps in the Federal Energy RD&D Portfolio" 40-43 (Information Technology and Innovation Foundation, November 2018), http://www2.itif.org/2018-innovation-agenda-decarbonization.pdf.
7. DOE, "FY 2020 Congressional Budget Justification" Volume 3 Part 2, 51-66.

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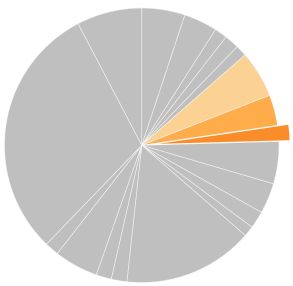
Federal Energy R&D: Hydrogen & Fuel Cells

BY COLIN CUNLIFF | APRIL 2019

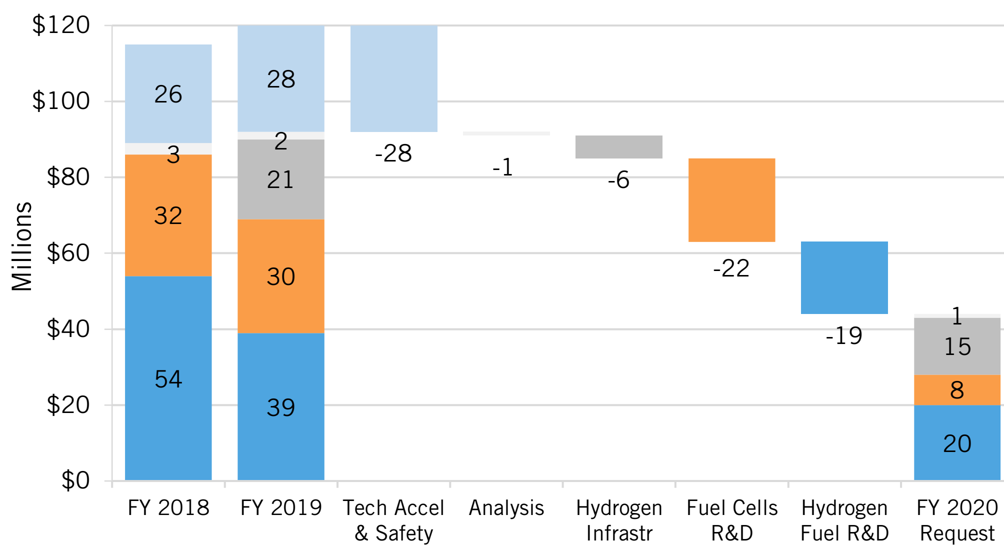
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



H2 and Fuels (orange)
Other Transportation (orange)
Energy R&D

Fuel cells use the chemical energy of hydrogen or similar fuel to cleanly and efficiently produce electricity. When hydrogen is the fuel, electricity, water, and heat are the only resulting products, with none of the carbon emissions or pollution emitted by conventional internal combustion engines. The Hydrogen & Fuel Cells program conducts R&D on three complementary technologies: low-cost hydrogen production from domestic resources; infrastructure for hydrogen compression, transmission, storage, and delivery; and fuel-cell technologies that can be used in electric vehicles and other applications.[1]

Figure 1: The FY 2020 Budget Request Would Cut Hydrogen and Fuel-cell R&D by 63 Percent[2]



What's At Risk

Innovations resulting from DOE R&D over the past decade have facilitated a more than 50 percent cost reduction in fuel cells. However, further reductions are necessary for fuel cells to become cost-competitive with internal combustion engine vehicles. DOE's goals include decreasing the modeled high-volume cost of automotive fuel cells to $30 per kilowatt ($30/kW) and improving fuel cell durability to 8,000 hours (approximately 240,000 miles of driving) by 2030. While the program's focus is on transportation, its R&D also benefits stationary fuel cells (such as those used to provide backup power), reversible fuel cells, and small-scale cells for tri-generation of fuel, heat, and power that may provide resilience and flexibility to multiple sectors.[3] Reductions in R&D funding threaten to delay DOE progress toward cost-competitive fuel cells.

DOE is also targeting a hydrogen production cost of $2 per gallon gasoline equivalent ($2/gge), with a system-wide cost (hydrogen production plus delivery) of $4/gge in order to be cost competitive with gasoline on a cents-per-mile driven basis.[4] Hydrogen also has important applications beyond the transportation sector, and is one of the few technology options for addressing harder-to-abate sources of carbon emissions.[5] Hydrogen can serve as a form of long-duration electricity storage, a feedstock in the production of synthetic hydrocarbon fuels and chemicals, and as a source of high-temperature heat for industrial applications.[6] Because of the wide range of end uses, hydrogen can facilitate greater integration of energy systems across sectors and has led many to call for creation of a "hydrogen economy."[7] However, realizing the enormous potential of hydrogen requires continued R&D in different hydrogen production and delivery systems.

Hydrogen & Fuel Cells R&D Subprograms

R&D in the Hydrogen & Fuel Cells program is distributed across six subprograms:[8]

- **Fuel Cell** supports R&D to develop technologies that enhance the durability, reduce the cost, and improve the performance of fuel cells, with a goal of achieving cost competitiveness with internal combustion engine light duty vehicles by 2030.
- **Hydrogen Fuel R&D** focuses on the development of novel hydrogen production and storage technologies, including hydrogen production by electrically splitting water, as well as direct conversion of natural gas to hydrogen and carbon co-products (beyond the conventional steam methane reforming process).
- **Hydrogen Infrastructure R&D** is a new subprogram established in FY 2019 that focuses on reducing costs of hydrogen fueling infrastructure systems, such as liquid pumps, compressors, storage, chillers, dispensers, and other hydrogen delivery and station components.
- **Systems Analysis** performs analytical research that provides a technical basis for informed decision-making for the program's R&D direction and prioritization.
- **Safety, Codes, and Standards** collaborates with government, industry, standards-development organizations, universities, and National Laboratories to harmonize regulations, codes, and standards (RCS), and develop best practices to ensure safety in the operation, handling, and use of hydrogen and fuel-cell technologies.
- **Technology Acceleration** supports technology transition from R&D to commercial viability through validation, evaluation, and testing of advanced hydrogen and fuel-cell technologies under real-world conditions.

Figure 1 displays recent and proposed funding levels for each of the subprograms, with the Technology Acceleration and Safety, Codes, and Standards subprograms displayed in a single entry (light blue).

Key Elements of the FY 2020 Budget Proposal

- **Elimination of the Safety, Codes, and Standards subprogram**, including R&D to develop safety codes and standards through the H-Mat Consortium, validate cryogenic hydrogen behavior models, improve existing quantitative risk assessment models, develop hydrogen sensor technologies, and address technical gaps for safety-related hydrogen infrastructure components.

- **Elimination of the Technology Acceleration subprogram**, including a first-of-a-kind demonstration of integrated renewable energy and hybrid hydrogen production systems, R&D on fueling technologies for heavy-duty applications, and industry-led projects to reduce the cost of electrolyzer manufacturing technologies.

- **A 73-percent reduction in Fuel Cell R&D**, including reduced funding for the Fuel Cell Performance and Durability (FC-PAD) consortium, as well as reduced focus on reversible fuel cells that can be used in power-to-gas-to-power systems.

- **A 49-percent reduction in the Hydrogen Fuel R&D subprogram,** including reduced funding for the HydroGEN Consortium, a collaborative effort between six national laboratories, industry, and university partners to identify new catalysts, membranes, and other materials to reduce the cost of water splitting.

- **A 29-percent reduction in the Hydrogen Infrastructure R&D subprogram,** including substantial reductions in funding for the Hydrogen Materials (H-Mat) consortium to identify materials for bulk storage and hydrogen dispensing, as well as reduced funding for dispensing technologies for heavy-duty applications and chemical carriers with improved hydrogen storage capacity. The proposal includes $5 million to fund electrolyzer integration R&D as part of the administration's proposed crosscutting Advanced Energy Storage Initiative.

ENDNOTES

1. DOE, "Congressional Budget Justification" Volume 3 Part 2, 79-100, (DOE Chief Financial Officer DOE/CF-0153, April 2019), https://www.energy.gov/sites/prod/files/2019/04/f61/doe-fy2020-budget-volume-3-part-2_0.pdf.
2. The Technology Acceleration ($21 million in FY 2019) and Safety, Codes and Standards ($7 million in FY 2019) subprograms are combined in a single entry in the waterfall chart. The administration is proposing to eliminate both in its FY 2020 budget request. The FY 2020 budget request for EERE would use $353 million in prior year (FY 2018 and FY 2019) balances to fund FY2020 programs. Thus the numbers shown in the figure underestimate the magnitude of cuts included in the proposed budget. Department of Energy, "FY 2020 Congressional Budget Request: Budget in Brief," (DOE CFO, March 2019), p 3, https://www.energy.gov/sites/prod/files/2019/03/f60/doe-fy2020-budget-in-brief.pdf; DOE, "FY 2020 Congressional Budget Justification" Volume 3 Part 2, 81.
3. DOE, "Congressional Budget Justification" Volume 3 Part 2, 83.

4. Ibid, 87-92.
5. Davis et al., "Net-zero emissions energy systems," Science **360** (2018), http://dx.doi.org/10.1126/science.aas9793.
6. David M. Hart, "Making 'Beyond Lithium' a Reality: Fostering Innovation in Long-Duration Grid Storage" (Information Technology and Innovation Foundation, November 2018), https://itif.org/publications/2018/11/28/making-beyond-lithium-reality-fostering-innovation-long-duration-grid; Colin Cunliff, "An Innovation Agenda for Deep Decarbonization: Bridging Gaps in the Federal Energy RD&D Portfolio" (Information Technology and Innovation Foundation, November 2018), 35-39, http://www2.itif.org/2018-innovation-agenda-decarbonization.pdf.
7. Mary-Rose de Valladares, "Global Trends and Outlook for Hydrogen" (International Energy Agency, December 2017), http://ieahydrogen.org/pdfs/Global-Outlook-and-Trends-for-Hydrogen_WEB.aspx.
8. DOE, "Congressional Budget Justification" Volume 3 Part 2, 79-100. Definitions for the Safety, Codes and Standards and Technology Acceleration subprograms are taken from the FY 2019 Congressional Budget Justification, since the proposed elimination of these subprograms has not received Congressional support during previous budget cycles. See DOE, "Congressional Budget Justification" Volume 3 Part 2, 103-106, (DOE Chief Financial Officer DOE/CF-0141, March 2018), https://www.energy.gov/sites/prod/files/2018/03/f49/FY-2019-Volume-3-Part-2.pdf.

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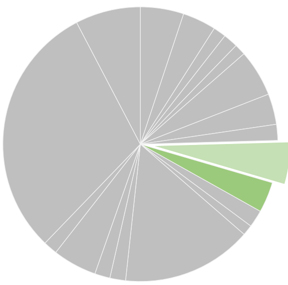
Federal Energy R&D: Advanced Manufacturing

BY COLIN CUNLIFF | APRIL 2019

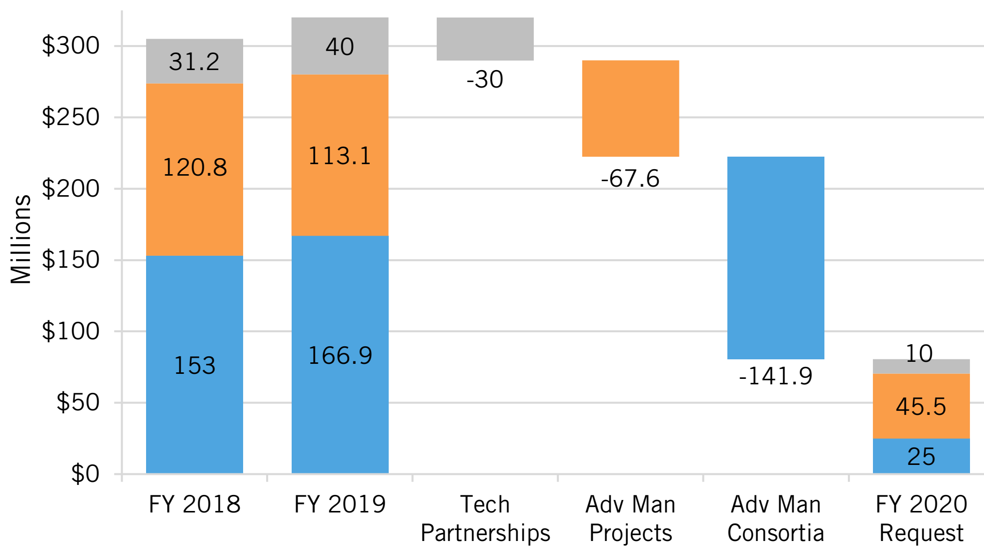
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



Manufacturing (light green)
Other Efficiency (green)
Energy R&D (light gray)

The Department of Energy's (DOE) Advanced Manufacturing Office (AMO) works to improve the energy efficiency and productivity of U.S. manufacturers by focusing R&D on cross-cutting, platform technologies relevant to manufacturing in multiple fields. A key goal is to ensure new energy technologies invented in the United States are also manufactured in the United States. AMO supports R&D through competitive funding opportunities designed to develop novel manufacturing technologies.[1]

Figure 1: The FY 2020 budget request would cut advanced manufacturing R&D by 75 percent[2]



What's At Risk

Manufacturing plays an outsize role in the health of the U.S. economy because of both its impact on trade and innovation, and its large multiplier effect on other sectors. Accelerated innovation in both industrial processes that use energy and products used by the energy industry would strengthen U.S. manufacturing and hasten progress toward national economic, workforce, security, and environmental goals. Market failures, however, lead to many gaps in the private-sector response to the manufacturing and energy innovation imperative, and have led to significant supply-chain weaknesses, regional hollowing out, and underinvestment in workforce education and training.

AMO helps address such market failures in several ways, with the goal of improving the energy productivity of U.S. manufacturing, reducing lifecycle energy and resource impacts of manufactured goods, and transitioning DOE-supported technologies and practices into

U.S. manufacturing. Together, these efforts assist manufacturers in cutting energy costs, which has already been an important driver in the "reshoring" of manufacturing to the United States over the past decade.[3]

Advanced Manufacturing R&D Subprograms

Unlike other DOE technology programs structured around technical focus areas, AMO subprograms are structured around modes of program implementation: individual R&D projects, collaborative R&D consortia, and technology partnerships.[4]

- **Advanced Manufacturing R&D Projects** focus on high-impact manufacturing technology and process challenges in areas such as advanced materials manufacturing for energy applications, improved energy-efficient process technologies, high-performance computing for manufacturing, additive manufacturing processes, roll-to-roll processing, wide bandgap power electronics, chemical and thermal process intensification, and structures used in extreme environments.

- **Advanced Manufacturing R&D Consortia** bring together manufacturers, research institutions, suppliers, and universities in public-private R&D partnership consortia, each of which focuses on a specific set of challenges at the nexus of manufacturing and energy. AMO consortia include the Manufacturing Demonstration Facility (MDF), which focuses on advanced manufacturing technologies to reduce energy and production costs; the Carbon Fiber Test Facility (CFTF); six Manufacturing USA institutes that focus on clean energy technologies; the Energy-Water Desalination Hub; and the Critical Materials Institute.[5]

- **Advanced Manufacturing Technical Partnerships** help small and medium-sized manufacturers improve their energy productivity and reduce waste and water use; demonstrate the viability of improved energy-management approaches; and promote combined heat and power (CHP) and waste heat to power technologies to improve efficiencies and lower energy costs.

Key Elements of the FY 2020 Budget Proposal

- **An 85-percent reduction in the Advanced Manufacturing Consortia,** including termination of the Critical Materials Institute, the Energy-Water Desalination Hub, and the six clean energy Manufacturing USA institutes. Reduced funding will support smaller and more directly-managed National Laboratory-based consortia that focus on power semiconductors, cybersecure process controls, water security, rare-earth materials, and other advanced materials. The topical areas for the proposed new consortia match the focal areas of existing consortia, with the primary difference being a shift away from working with industry and university partners. But industry collaboration is essential for ensuring that the results of laboratory R&D transfer into actual manufacturing capabilities. This new model for laboratory-based consortia will likely not realize the full benefit of U.S. investment in manufacturing R&D.[6]

- **Reduced funding for public-private R&D projects at the Manufacturing Demonstration Facility (MDF) and the Carbon Fiber Test Facility (CFTC),** including a shift toward early-stage R&D.

- **A 60-percent reduction in Advanced Manufacturing R&D Projects**, with reduced R&D in roll-to-roll manufacturing processes, efficient drying technologies, materials operating in harsh environments, and reduced funding to support early-career post-doctoral researchers. Remaining funding will focus on manufacturing advanced thermoelectric generation system components and new energy storage technologies, including support for the administration's crosscutting Advanced Energy Storage Initiative.

- **Elimination of the Industrial Assessment Centers (IACs) and the Combined Heat-and-Power Technical Assistance Partnerships (CHP TAPs),** which provide technical assistance to small and medium-sized manufacturers to improve resilience and lower energy costs. Overall funding for the Technical Partnerships subprogram would decline by 75 percent.

ENDNOTES

1. DOE, "FY 2020 Congressional Budget Justification" Volume 3 Part 2, 163-172 (DOE Chief Financial Officer DOE/CF-0153, April 2019), https://www.energy.gov/sites/prod/files/2019/04/f61/doe-fy2020-budget-volume-3-part-2_0.pdf.
2. The FY2020 budget for EERE would use $353 million in prior year (FY 2018 and FY 2019) balances to fund FY2020 programs. Thus the numbers shown in the figure underestimate the magnitude of cuts included in the proposed budget. Department of Energy, "FY 2020 Congressional Budget Request: Budget in Brief," (DOE CFO, March 2019), p 3, https://www.energy.gov/sites/prod/files/2019/03/f60/doe-fy2020-budget-in-brief.pdf; DOE, "FY 2020 Congressional Budget Justification" Volume 3 Part 2, 165.
3. Stephen Ezell, Robert Atkinson, and David M. Hart, "ITIF Comments Responding to Administration RFI for National Strategic Plan for Advanced Manufacturing," (Information Technology and Innovation Foundation, 2018), http://www2.itif.org/2018-comments-national-strategic-plan-advanced-manufacturing.pdf.
4. DOE, "FY 2020 Congressional Budget Justification" Volume 3 Part 2, 163-172.
5. The Manufacturing USA initiative refers to a network of 15 manufacturing institutes sponsored by the Department of Defense (DOD), the National Institutes of Standards and Technology (NIST), and DOE. The six Manufacturing USA institutes hosted by DOE are commonly called the clean energy manufacturing innovation (CEMI) institutes. For more on the relationship between the CEMI institutes and the larger Manufacturing USA network, see David M. Hart and Peter L. Singer, "Manufacturing USA at DOE: Supporting Energy Innovation" (Information Technology and Innovation Foundation, May 2018), http://www2.itif.org/2018-doe-musa-institutes.pdf.
6. Hart and Singer, "Manufacturing USA at DOE: Supporting Energy Innovation."

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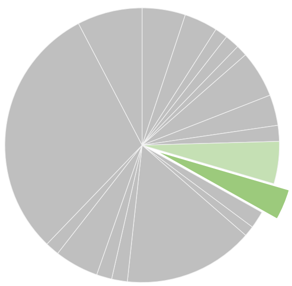
Federal Energy R&D: Building Technologies

BY COLIN CUNLIFF | APRIL 2019

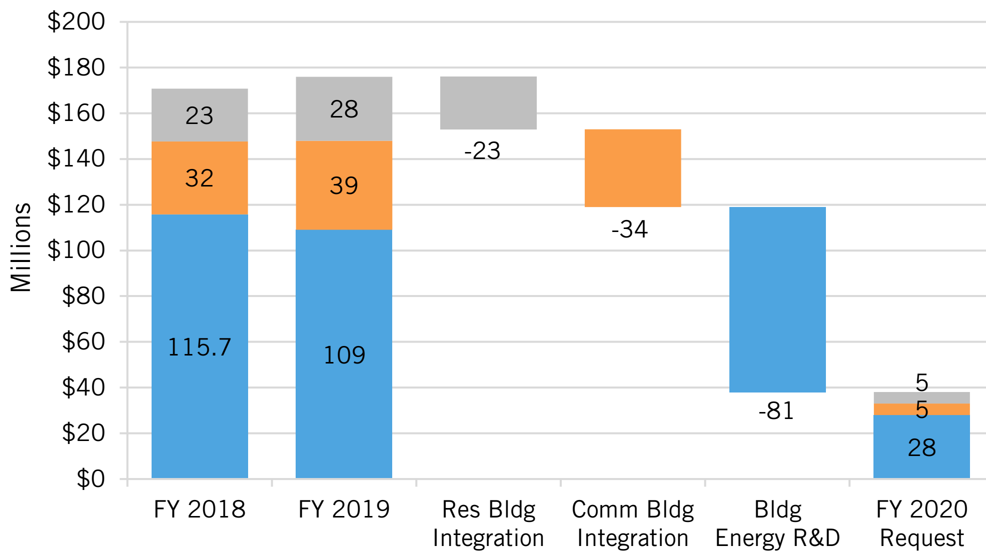
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



Buildings (green)
Other Efficiency (green)
Energy R&D (light gray)

The Department of Energy's (DOE) Building Technologies Office (BTO) invests in research and development (R&D) of novel technologies that are designed to improve the efficiency and reduce the energy costs of the nation's residential and commercial buildings—particularly the largest energy users therein: lighting, space conditioning and refrigeration, water heating, appliances, and miscellaneous electric loads (MELs), as well as the building envelopes themselves. BTO also works on improved energy modeling and system controls to predict and manage energy-efficient appliance/equipment, system, and whole-building energy usage.[1]

Figure 1: The FY 2020 Budget Request Would Cut Building Technologies R&D by 78 Percent.[2]



What's At Risk

Residential and commercial buildings are the single largest energy-consuming sector in the U.S. economy, accounting for roughly 75 percent of the nation's electricity use and 40 percent of its total energy demand.[3] As a result, Americans spend nearly $400 billion each year to power their homes, offices, schools, hospitals, and other buildings.[4] The Building Technologies program has established the ambitious goal of reducing the average energy use per square foot of commercial buildings by 30 percent by 2030, and that of new single-family homes by 60 percent and existing homes by 40 percent by 2020.[5] In addition to these whole-building targets, the Building Technologies Office (BTO) is pursuing substantial improvements to the efficiency of energy services within buildings, including lighting (65 percent improvement); water heating (35 percent); heating, ventilation, and air conditioning (HVAC) (25 percent); building envelope and windows (35 percent); appliances (30 percent); and sensors and controls (20 percent).[6] Achieving these goals by 2030 would decrease total energy use by 5 quadrillion BTUs, cut carbon emissions by 450 million metric tons, and save consumers over $100 billion annually in energy costs.[7]

BTO also supports collaborative partnerships through the Better Buildings Initiative (BBI) to accelerate new innovations and develop new resources to lower energy costs. Through BBI, DOE has partnered with more than 900 organizations, including businesses, schools, hospitals, state and local governments, public housing authorities, retailers and grocery stores, and residential organizations across the country. BBI partners represent 30 of the country's Fortune 100 companies, 12 of the top 25 U.S. employers, 12 percent of the U.S. manufacturing footprint, and 13 percent of total commercial building space, as well as 17 federal agencies, 28 states, and 93 local governments. As a result of innovative energy solutions developed through BBI, commercial and industrial partners have reported an estimated cost savings of $7.3 billion in energy savings since 2011, while partnerships with other federal agencies have resulted in $12.3 billion in cumulative energy cost savings.[8]

Building Technologies R&D Subprograms

BTO R&D activities are divided among three main subprograms:[9]

- **Building Energy R&D (BERD)** sponsors R&D in energy-efficient building technologies: Buildings-to-Grid; heating, ventilation and air-conditioning & refrigeration (HVAC&R); windows & envelope; solid-state lighting; and Building Energy Modeling (BEM).

- **Commercial Buildings Integration (CBI)** conducts R&D and analytical studies of building systems (e.g., lighting, HVAC, envelope, sensors and controls) and whole commercial buildings (e.g., office buildings, schools, hospitals, stores, warehouses, public infrastructure buildings) to assess the interactive effects of combining multiple novel technologies within a commercial building system, and also supports commercial building partnerships through the Better Buildings Initiative programs to develop and demonstrate innovative energy-saving technologies and solutions.

- **Residential Buildings Integration (RBI)** conducts R&D to identify technology areas and technical solutions that offer the potential for large energy savings in new and existing homes, and works to demonstration and validate innovative technology solutions through its Building America, Zero Energy Ready Homes, and Better Buildings Initiatives.

Key Elements of the FY 2020 Budget Proposal

- **An 87-percent reduction in the Commercial Buildings Integration subprogram,** including elimination of all later-stage development and commercialization activities, such as the High Impact Technology innovation Catalyst (HIT Catalyst) program which supports demonstration and validation of building systems optimization and advanced technology solutions.[10] It is unclear whether commercial-sector partnerships through the Better Buildings Initiative would continue under the current budget proposal.

- **An 82-percent reduction in the Residential Buildings Integration subprogram,** including elimination of all later-stage development and commercialization activities such as Home Performance with ENERGY STAR, Better Buildings Residential, and demonstration efforts with industry partners. Funding for R&D on next generation retrofits of existing buildings, as well as the Solar Decathlon collegiate competition to design and build new highly-efficient solar-powered homes, would also be eliminated.

- **A 74-percent reduction in Building Energy R&D**, with substantial reductions across all technology focus areas, including lighting, HVAC and refrigeration, buildings-to-grid, building envelope and windows, and building energy modeling. Remaining funding would primarily support early-stage research at the national laboratories, while competitive funding opportunities and joint R&D partnerships with industry and university researchers would be severely curtailed or eliminated altogether.

ENDNOTES

1. Department of Energy (DOE), "FY 2020 Congressional Budget Justification" Volume 3 Part 2, 183 (DOE Chief Financial Officer DOE/CF-0153, April 2019), https://www.energy.gov/sites/prod/files/2019/04/f61/doe-fy2020-budget-volume-3-part-2_0.pdf.
2. The FY2020 budget for EERE would use $353 million in prior year (FY 2018 and FY 2019) balances to fund FY2020 programs. Thus the numbers shown in the figure underestimate the magnitude of cuts included in the proposed budget. Department of Energy, "FY 2020 Congressional Budget Request: Budget in Brief," (DOE CFO, March 2019), p 3, https://www.energy.gov/sites/prod/files/2019/03/f60/doe-fy2020-budget-in-brief.pdf; DOE, "FY 2020 Congressional Budget Justification" Volume 3 Part 2, 186 (DOE Chief Financial Officer DOE/CF-0153, April 2019), https://www.energy.gov/sites/prod/files/2019/04/f61/doe-fy2020-budget-volume-3-part-2_0.pdf.
3. Energy Information Administration (EIA), "Monthly Energy Review" Table 2.1 and 7.6, (DOE EIA, Release Date March 26, 2019), https://www.eia.gov/totalenergy/data/monthly/.
4. DOE, "FY 2020 Congressional Budget Justification" Volume 3 Part 2, 183.
5. Ibid, 197-201.
6. These goals were included in the FY 2017 Congressional Budget Justification and were informed by BTO's FY 2016-FY 2020 Multi-Year Program Plan, but have not been included in subsequent

Congressional Budget Justification documents. DOE, "FY 2017 Congressional Budget Justification" Volume 3, 217, (DOE Chief Financial Officer DOE/CF-0121, February 2016), https://www.energy.gov/sites/prod/files/2016/02/f29/FY2017BudgetVolume3_2.pdf; DOE Building Technologies Office, "BTO Multi-Year Program Plan" (DOE BTO, January 2016), https://www.energy.gov/sites/prod/files/2016/02/f29/BTO_MYPP_2016.pdf.

7. DOE, "Building Technologies Office FY 2017 Budget At-A-Glance" (Washington, D.C.: Department of Energy, Energy Efficiency and Renewable Energy, March 2016), https://www.energy.gov/sites/prod/files/2016/03/f30/At_A_GLANCE%20%28BTO%29.pdf.

8. Numbers reflect savings through the Better Buildings Challenge and Better Buildings, Better Plants programs. DOE, "2018 Better Buildings Progress Report: Innovation Through Collaboration: Securing a More Affordable and Reliable Energy Future" (DOE, 2018), 2 https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/DOE_BBI_2018_Progress_Report_051018.pdf.

9. The Building Technologies Office also houses the Equipment and Building Standards subprogram, a regulatory program which sets energy efficiency standards for appliances, equipment, and processes. Because this program is regulatory in nature, it is not included in our assessment of federal R&D. The current administration has attempted to eliminate the Commercial and Residential Buildings Integration programs during the last two budget cycles, but this proposal has been rejected by Congressional appropriators. For more information, see DOE, "FY 2018 Congressional Budget Justification" Volume 3, 211-214 (DOE Chief Financial Officer DOE/CF-0130, May 2017) https://www.energy.gov/sites/prod/files/2017/05/f34/FY2018BudgetVolume3_0.pdf; and DOE, "BTO's Program Areas" https://www.energy.gov/eere/buildings/building-technologies-office, accessed April 10, 2019.

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ACKNOWLEDGMENTS

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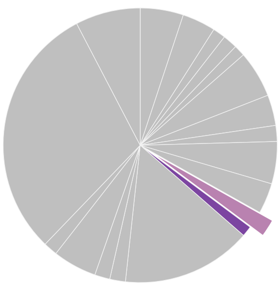
Federal Energy R&D: Grid Modernization

BY COLIN CUNLIFF | APRIL 2019

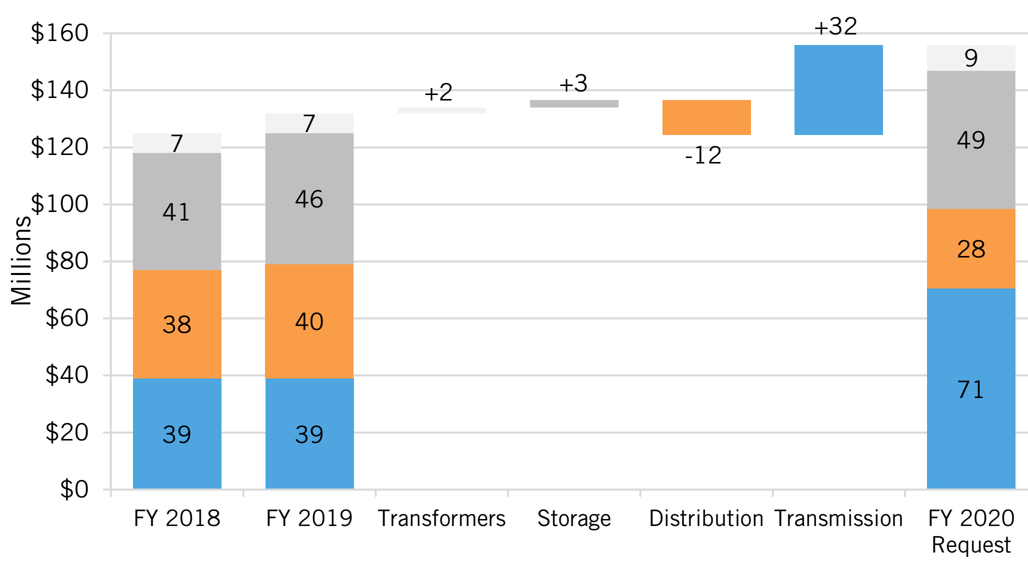
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



Grid Mod (lavender)
Energy TS&D
Energy R&D (light gray)

The grid modernization R&D programs in the Office of Electricity (OE) accelerate discovery and innovation in electric transmission and distribution technologies to incorporate greater levels of distributed and variable energy resources, provide enhanced connectivity between systems and devices, and improve reliability and resilience. OE seeks to provide solutions to market, institutional, and operational failures that go beyond any one utility's ability to solve.[1] The program's work on resilience, threat assessment, risk management, and grid hardening is motivated by natural disasters, such as hurricanes Harvey and Maria and Superstorm Sandy, as well as the 2013–2015 drought and accompanying wildfires in the western United States. The OE-funded R&D into energy-storage technologies aims to enable greater stability, resiliency, and reliability in the electric grid, while also supporting increasing levels of variable renewable energy sources such as wind and solar.[2]

Figure 1: The FY 2020 Budget Request Would Increase Grid Modernization R&D by 18 Percent.[3]



What's At Stake

Grid modernization is critical to ensuring reliable and affordable energy delivery, sustaining economic growth, and mitigating risks to the security of the grid and other vital sectors that depend on the grid's services. In collaboration with the utility industry, DOE established the Grid Modernization Initiative to coordinate R&D activities. Through the initiative, a multiyear R&D roadmap outlining six technical areas (devices and integrated systems testing; sensing and measurements; system operations, power flow, and control; design and planning tools; security and resilience; and institutional support) that industry and government should jointly pursue to establish a resilient, secure, sustainable, and reliable grid was created.[4] For its part, DOE has set aggressive targets and performance measures in reliability and resilience, as well as cost and performance targets for new grid-storage technologies.[5]

Grid Modernization R&D Subprograms

Grid modernization R&D is made up of four main subprograms:[6]

- **Transmission Reliability and Resilience (TRR)** focuses on ensuring the reliability and resilience of the U.S. electric grid through R&D on measurement and control of the electrical system, and risk assessments to address challenges across integrated energy systems.
- **Resilient Distribution Systems (RDS)** pursues strategic R&D to improve reliability, resiliency, outage recovery, and operational efficiency of the distribution portion of the electricity-delivery system, with a focus on improved resilience against extreme weather and other natural and man-made hazards.
- **Energy Storage** focuses on the development of new materials and device technologies that both improve the cost and performance of utility-scale energy-storage systems and better integrate storage into the grid infrastructure.
- **Transformer Resilience and Advanced Components (TRAC)** supports modernization, hardening, and resilience of grid components, including transformers, power lines, and substation equipment.

Key Elements of the FY 2020 Budget Proposal[7]

- **An 81-percent increase in Transmission Reliability and Resilience**, including the development of an integrated North American Energy Resiliency Model (NAERM) to improve planning and contingency analyses that address energy system vulnerabilities; new R&D efforts on transmission sensors and data analytics; and reduced activities in synchrophasor tools.
- **A 30-percent reduction in Resilient Distribution Systems**, with ongoing support for the development of GridAPPS-D, an open-source advanced distribution management system that can manage greater levels of distributed energy resources (DERs), and a discontinuation of R&D activities in advanced low-cost distribution sensors, and university-based R&D of sensing, intelligent machines in the Internet of Things.
- **A 5-percent increase in Energy Storage,** including $5 million for design and construction planning of a new Grid Storage Launchpad to accelerate materials

development, testing, and evaluation of battery materials and systems; and a $2.5 million decrease in research in next-generation flywheels, storage valuation models, and the development of "second use" grid applications for batteries from retired electric vehicles.[8]

- **A 29-percent increase in Transformer Resilience and Advanced Components**, which currently conducts research on grid-component vulnerabilities to geomagnetic disturbances (GMD) and electromagnetic pulses (EMP), as well as R&D on improving the resilience of large power transformers—which are one of the most vulnerable components of the grid and would pose a significant risk to the nation in the event of multiple failures.[9]

ENDNOTES

1. For example, individual utilities and grid operators lack the wide-area visibility that could have minimized the 2003 Northeast blackout, or the modeling and analytical tools identified as necessary for containing the 2011 Southwest blackout.
2. DOE, "FY 2020 Congressional Budget Request," Volume 3 Part 1, DOE/CF-0152 (Washington, D.C.: DOE Chief Financial Officer, March 2019), 9-43, https://www.energy.gov/sites/prod/files/2019/03/f61/doe-fy2020-budget-volume-3-part-1_2.pdf.
3. DOE, FY 2020 Congressional Budget Request Volume 3 Part 1, 13.
4. DOE, "Grid Modernization Multi-Year Program Plan" (Washington, D.C.: November 2015), https://www.energy.gov/sites/prod/files/2016/01/f28/Grid%20Modernization%20Multi-Year%20Program%20Plan.pdf.
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6. DOE, FY 2020 Congressional Budget Request Volume 3 Part 1, 9-43.
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8. David M. Hart, "Energy Storage RD&D in the Fiscal Year 2020 Budget Proposal," (Information Technology and Innovation Foundation, March 2019), https://itif.org/publications/2019/03/27/energy-storage-rdd-fiscal-year-2020-budget-proposal.
9. DOE, "Strategic Transformer Reserve Report to Congress" (Washington, D.C.: March 2017), https://www.energy.gov/oe/downloads/strategic-transformer-reserve-report-congress-march-2017.

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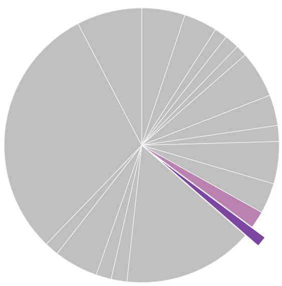
Federal Energy R&D: Cybersecurity for Energy Systems

BY COLIN CUNLIFF | APRIL 2019

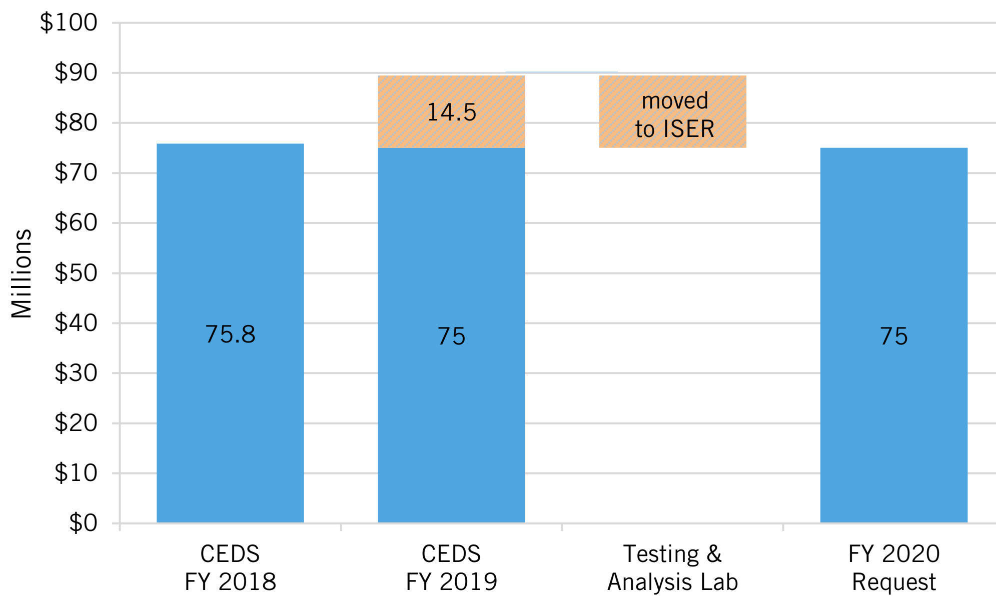
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



Cyber (purple)
Electricity TS&D
Energy R&D (light gray)

The goal of the Cybersecurity for Energy Delivery Systems (CEDS) program is to reduce the risk of energy disruptions from cyber events. Through CEDS, the Department of Energy (DOE) directly collaborates with energy-sector utility owners, operators, and vendors to strengthen the cybersecurity of critical energy infrastructure against current and future threats.[1]

Figure 1: The FY 2020 Budget Request Would Maintain Flat Funding for Cybersecurity for Energy Delivery Systems R&D.[2]



What's At Stake

The energy sector has been subjected to a dramatic increase in focused cyber probes, data exfiltration, and malware attacks in recent years. Previous rounds of threats have been aimed at information technology (IT) systems (e.g., email and business applications) at energy companies, but a new wave of cyberattacks is targeting operating technologies (OT), including software and hardware that directly control equipment on the grid. The cyberattack on the Ukrainian electricity-distribution system in December 2015 caused the first-ever cyber-linked blackout—and demonstrated the vulnerability of power grids to cyber events.[3]

In March 2018, the Department of Homeland Security (DHS) accused Russian government cyber actors of targeting critical U.S. infrastructure, including the electrical grid and nuclear power plants, highlighting the need for greater cybersecurity.[4] In September 2018, the White House released the *National Cyber Strategy of the United States* to help federal agencies coordinate efforts, define roles and responsibilities, and prioritize cybersecurity efforts.[5] Recent events indicate the need for strong federal support to coordinate efforts between the intelligence community and energy utilities to improve cybersecurity of critical energy systems infrastructure.[6]

Cybersecurity R&D Activities

In FY 2019, CEDS focused on these key research activities:[7]

- **Cybersecurity Risk Information Sharing Program (CRISP)** develops situational-awareness tools and facilitates the near-real-time sharing of cyber-threat information with energy owners and operators—such that they can promptly analyze the data and receive machine-to-machine mitigation measures.

- **Cyber Analytics Tools and Techniques (CATT)** supports utility data migration into the Intelligence Community Information Technology Environment (IC ITE), which provides a common platform for the intelligence community to easily and securely share analytic tools and technologies, information, and resources.

- **Cybersecurity for the Operational Technology Environment (CYOTE) Pilot** monitors utility data in the complex OT environment to identify malicious actions and aims to design an approach for collecting and sharing OT data.

- **Advanced Industrial Control System Analysis Center** develops capabilities to assess energy components and energy sector supply chain for vulnerabilities and to mitigate and respond to system threats.

Additionally, CEDS previously funded an energy delivery system testing and analysis laboratory (orange in figure 1) that is being moved to ISER.

Key Elements of the FY 2020 Budget Proposal

The new Cybersecurity, Energy Security, and Emergency Response (CESER) office houses the Cybersecurity for Energy Delivery Systems (CEDS) R&D program, as well as the Infrastructure Security and Energy Restoration (ISER), an energy-sector emergency-support function that does not include R&D activities. Elements of CEDS's proposed budget include:[8]

- Transferring the $14.5 million energy delivery system testing and analysis laboratory from CEDS to ISER for operationalizing the results of CEDS R&D activities;

- Discontinuing the DarkNet project to secure communications based on optical fibers;

- Discontinuing the Automated System R&D project to isolate automated systems and remove vulnerabilities;
- New funding for the Advanced Threat Mitigation initiative that aims to detect and mitigate high-risk threats faster by improving the speed and effectiveness of public-private information sharing;
- New funding that supports demonstrating and refining cybersecurity solutions for energy sector entities that provide power to military and government installations.

ENDNOTES

1. DOE, "FY 2020 Congressional Budget Request," Volume 3 Part 1, DOE/CF-0152 (Washington, D.C.: DOE Chief Financial Officer, March 2019), 65-77, https://www.energy.gov/sites/prod/files/2019/03/f61/doe-fy2020-budget-volume-3-part-1_2.pdf.
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3. For a description of the Ukraine hacking and its implications for the U.S. electric sector, see the E&E News Special Report by Peter Behr and Blake Sobczak, "The Hack," (E&E News Special Report, Washington, D.C.: July 2016), https://www.eenews.net/special_reports/the_hack.
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5. The White House, "National Cyber Strategy of the United States of America," (White House, September 2018), https://www.whitehouse.gov/wp-content/uploads/2018/09/National-Cyber-Strategy.pdf.
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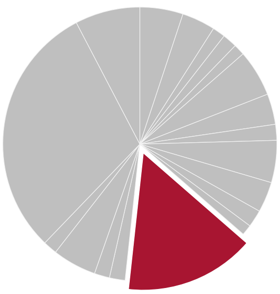
Federal Energy R&D: Nuclear Energy

BY COLIN CUNLIFF | APRIL 2019

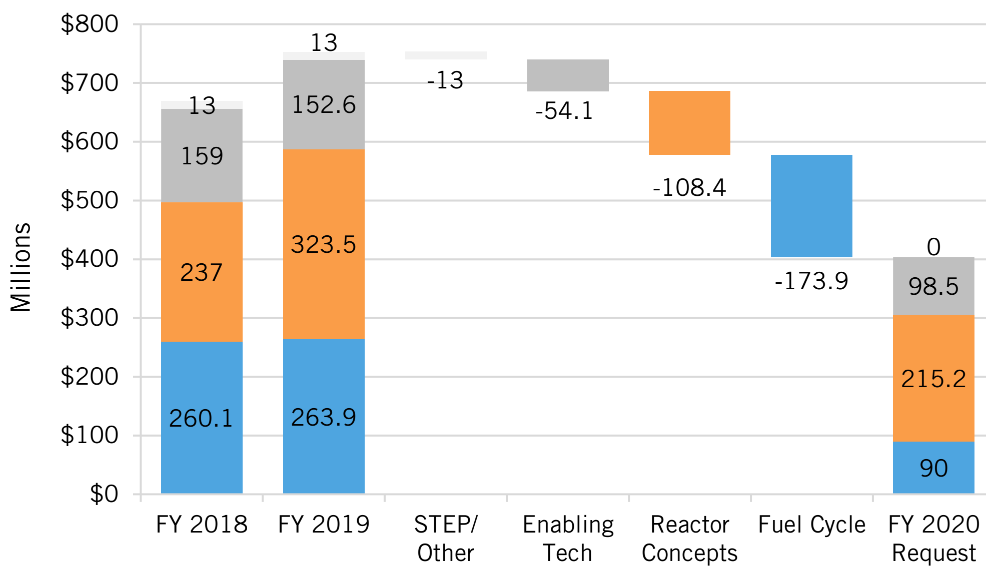
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



Nuclear Energy R&D (red)
Energy R&D (gray)

Nuclear power accounts for 19 percent of the electricity generated in the United States, and 54 percent of all carbon-free electricity.[1] Despite this success, the existing nuclear fleet is being challenged by low-cost natural gas and renewables, at the same time that Russia and China are outpacing the United States in the development of advanced next-generation nuclear reactors.[2] To address these challenges, the Department of Energy's (DOE) nuclear energy (NE) program conducts R&D on technical challenges with maintaining the existing reactor fleet, and on the development of a robust pipeline of advanced reactor designs and supply-chain capabilities.[3]

Figure 1: The FY 2020 Budget Request Would Cut Nuclear Energy R&D by 46 Percent.[4]



What's At Risk

Nuclear energy has unique regulatory challenges that limit the ability of the private sector to conduct full-scale R&D on its own. Plus, many of the facilities necessary for R&D are capital-intensive and lie beyond the financial capacity of potential nuclear innovators. DOE has had success working with industry to develop small modular reactors (SMRs) based on current light-water-reactor technologies. The SMR Licensing Technical Support program, for example, addressed first-of-a-kind costs associated with design certification and licensing, resulting in the submission of the first SMR design certification application to the Nuclear Regulatory Commission in January 2017. Design certification review is expected to be completed by January 2021, with the first SMR module expected to begin operating in 2026.[5]

DOE is exploring advanced, non-light-water reactor designs that could operate at higher temperatures (allowing for greater efficiency and provision of other energy services, such as process heating), produce lower volumes of waste, incorporate passive safety features, and reduce proliferation risks. However, DOE has conducted R&D in advanced reactors since the late 1990s, and so far no advanced reactor concepts have progressed to full-scale demonstration, let alone commercialization.[6]

Recent action in Congress and by the administration aims to jumpstart innovation in advanced nuclear technologies. In the last budget cycle, the administration proposed a new R&D subprogram focused on advanced (non-light-water) SMRs, to which Congress appropriated $100 million in its FY 2019 budget. In September 2018, Congress passed the Nuclear Energy Innovation Capabilities Act to facilitate private-sector innovation in advanced reactor technologies.[7] And in March 2019, a bipartisan group of 15 senators introduced the Nuclear Energy Leadership Act to spur the development and demonstration of new nuclear technologies.[8] But these efforts are jeopardized without greater levels of sustained funding for nuclear energy R&D.

Nuclear Energy R&D Subprograms

Nuclear energy R&D is conducted in the following subprograms:[9]

- **Reactor Concepts RD&D** develops new and advanced reactor designs and technologies, including advanced SMRs, fast reactors using liquid-metal coolants, high-temperature reactors, and micro-reactor technologies. The subprogram also houses a new effort, launched in FY 2018, to build and operate a Versatile Advanced Test Reactor user facility to enable testing of materials and fuel designs in a fast-neutron environment.

- **Fuel Cycle R&D** studies advanced fuel-cycle technologies that have the potential to enhance safety, improve resource utilization, reduce waste generation, and limit risk of proliferation.

- **Nuclear Energy Enabling Technologies** works to develop cross-cutting technologies in reactor materials, advanced sensors and instrumentation, innovative manufacturing and construction technologies, advanced cooling concepts, and modeling and simulation—and provides support for nuclear-science user facilities.

- **Supercritical Transformation Electric Power (STEP) and other NE R&D** includes contributions to the cross-cutting STEP program, which develops supercritical carbon dioxide Brayton cycle technologies (which are potentially applicable to nuclear, concentrated-solar, bio-, geothermal, and fossil-fuel power), as well as nuclear-workforce training and education programs.

Key Elements of the FY 2020 Budget Proposal

- **A 66-percent reduction in Fuel Cycle R&D**, including reduced funding for advanced nuclear fuels, material recovery and waste-form development, used nuclear fuel disposition R&D, as well as elimination of systems analysis and integrated waste management activities. Funding to demonstrate the capability to produce high-assay low-enriched uranium (HA-LEU) domestically would receive a boost.

- **A 33-percent reduction in Reactor Concepts R&D**, including reduced funding for light-water-reactor sustainability and advanced-reactor technologies; a 90-percent reduction in the Advanced Small Modular Reactor program; and an increase in funding for the Versatile Advanced Test Reactor.

- **A 35-percent reduction in Nuclear Energy Enabling Technologies**, including elimination of the Energy Innovation Hub for Modeling and Simulation; large reductions in crosscutting technology development and nuclear science user facilities; and creation of a new Transformational Challenge Reactor activity to develop advanced manufacturing methods for small- and micro-reactors.

- **Elimination of the STEP and nuclear-workforce development programs.**

ENDNOTES

1. EIA, "Monthly Energy Review," Table 7.2a, (Washington, D.C.: EIA, Release Date March 26, 2019), http://www.eia.gov/mer. Accessed April 10, 2018.
2. Russia currently operates two sodium-cooled fast reactors: the 600 megawatt BN600 which began operation in 1980, and the 800 megawatt BN800 which entered commercial operation in 2016. China is operating an experimental 20 megawatt fast reactor—which began operations in 2011—and is designing a 1,000 megawatt prototype fast reactor. For more on advanced nuclear technologies, see International Energy Agency, "Nuclear Energy Technology Roadmap," (IEA and the Nuclear Energy Agency, 2015), https://webstore.iea.org/technology-roadmap-nuclear-energy-2015.
3. DOE, "FY 2020 Congressional Budget Justification" Volume 3 Part 2, 265, (DOE Chief Financial Officer, DOE/CF-0153, April 2019), https://www.energy.gov/sites/prod/files/2019/04/f61/doe-fy2020-budget-volume-3-part-2_0.pdf.
4. Ibid, 267.
5. NuScale expects to file a combined construction and operation license application (COLA) in 2019, allowing the design certification and COLA review processes to proceed concurrently. Karen Thomas, "NuScale files US' first SMR License Application as Suppliers Await Tender," *Nuclear Energy Insider*, January 10, 2017, https://analysis.nuclearenergyinsider.com/nuscale-files-us-first-smr-license-application-suppliers-await-tender; NuScale, "Licensing" https://www.nuscalepower.com/technology/licensing, accessed April 10, 2019.
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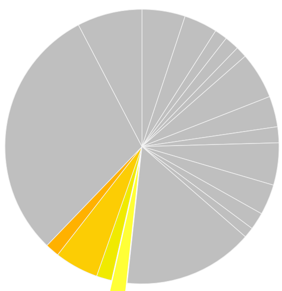
Federal Energy R&D: Carbon Capture

BY COLIN CUNLIFF | APRIL 2019

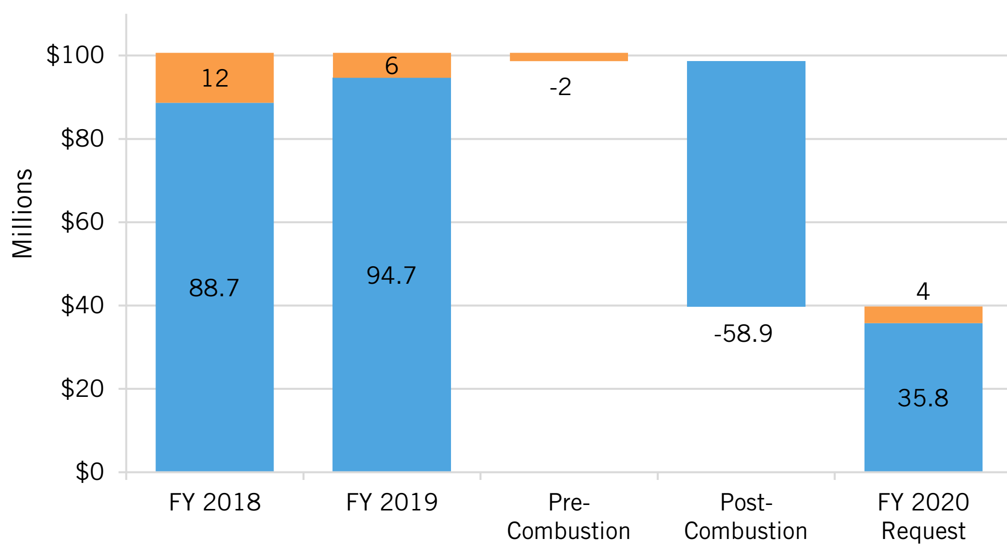
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



Carbon Capture (yellow)
Other Fossil (yellow)
Energy R&D (light gray)

Carbon capture, utilization, and storage (CCUS) technologies for fossil-fuel power plants have the potential to preserve important options—including coal- and natural gas-fired electricity generation—in a carbon-constrained future. CCUS is also the only option for decarbonizing many industrial processes—such as the production of ethanol, fertilizers, plastics, cement, and steel—for which zero-carbon alternatives do not exist.[1] The recent Intergovernmental Panel on Climate Change (IPCC) special report on 1.5°C of warming found that CCUS technologies play an essential role in nearly all deep decarbonization pathways.[2] DOE's carbon-capture RD&D program focuses on two complementary technologies for coal-fired power plants: pre-combustion systems, in which coal is gasified to allow for the removal of carbon dioxide (CO_2) prior to combustion or use in fuel cells; and post-combustion capture, which removes CO_2 from flue gas after combustion.

Figure 1: The FY 2020 Budget Request Would Cut Carbon Capture R&D by 60 Percent.[3]



What's At Risk

CCUS may be on the cusp of significant new buildouts and cost reductions. DOE's Industrial Carbon Capture and Storage (ICCS) program culminated in the successful launch of CCUS demonstration projects at the Port Arthur fertilizer facility in 2013 and the Archer Daniels Midland ethanol plant in 2017.[4] The world's largest successful post-combustion carbon-capture facility came online at the Petra Nova coal power plant in Texas in 2017.[5] A new pilot-scale natural gas oxy-combustion demonstration began operating at the NET Power facility in Texas in 2018.[6] And in February 2018, Congress expanded and extended the 45Q tax credit to incentivize greater utilization and storage of captured CO_2.[7]

However, continued improvement and cost reductions must occur before CCUS will be viable for full-scale deployment. Even with the 45Q tax credit, current state-of-the-art technologies for capturing and storing carbon emissions are still too expensive to spur widespread deployment in the largest emitting sectors, particularly power plants and cement and steel production.[8] While many of the research needs for carbon capture are crosscutting across all sources, what works for a coal power plant is not directly portable to a natural gas plant or other industrial sources such as cement and steel production plants. Integrating and optimizing carbon capture technologies with other sources faces technical hurdles unique to each source that must be addressed through pilot-scale demonstrations.[9]

DOE has set the ambitious target of reducing the cost of carbon capture to less than $40 per metric ton of CO_2 by 2025—and under $30 per metric ton by 2035.[10] Additionally, DOE has sought to establish international leadership in CCUS technologies through its participation in the Clean Energy Ministerial and Mission Innovation.[11] Reductions in R&D funding, and a shift away from demonstration projects, threaten to delay or even derail current DOE progress toward these targets and cede U.S. leadership in the emerging global CCUS industry.

Carbon Capture R&D Activities

R&D in carbon capture is spread across two activities:

- **Post-Combustion Capture Systems** focuses on separating and capturing CO_2 from flue gas after the fuel has been combusted, and can be used to retrofit existing fossil-fuel power plants. Because CO_2 makes up only 3-4 percent of flue gas from natural gas plants and 12-15 percent of flue gas from coal plants, separation is challenging—and once separated, the pure CO_2 must then be compressed for sequestration.[12] Recent funding has gone to the development of second-generation technologies for these functions, including pilot tests at the National Carbon Capture Center, as well as their integration with advanced power cycles and environmental control technologies for other pollutants.[13]

- **Pre-Combustion Capture Systems** focuses on removing CO_2 from fossil fuels before combustion is complete. Coal can be gasified under high pressure to produce a mixture of hydrogen (H_2) and highly concentrated CO_2, with the former used for energy storage and fuel, and the CO_2 captured and sequestered. Recent R&D has focused on advanced solvents, sorbents, and membranes to lower the cost of CO_2 separation for pre-combustion systems.

Activities in the Carbon Capture program are tightly coupled with R&D in advanced energy systems. Solid oxide fuel cells (SOFCs), gasification systems, oxy-combustion and chemical looping combustion, and direct-fired supercritical CO_2 cycles (i.e., the Allam cycle), are all designed and optimized to integrate with carbon capture technologies.[14]

Key Elements of the FY 2020 Budget Proposal

- **A discontinuation of all large-scale demonstrations, pilot projects, and similar ventures that address technology scale-up and commercialization.** However, demonstration of carbon capture systems at full scale is necessary to establish cost, reliability, and performance characteristics and optimize integration with industrial and power sector carbon sources.

- **A 60-percent reduction in Post-Combustion Capture Systems**, including a shift away from 2nd generation amine capture systems. The budget proposes refocusing on early-stage research and bench-scale development of non-aqueous solvents, membranes, advanced sorbents, and cryogenic processes with the potential to reduce the cost of CO_2 capture.[15]

- **A 33-percent reduction in Pre-Combustion Capture Systems,** including a discontinuation of all large-scale demonstrations and pilot projects. No funding is requested for activities to scale up pre-combustion technologies beyond bench-scale demonstrations.[16]

ENDNOTES

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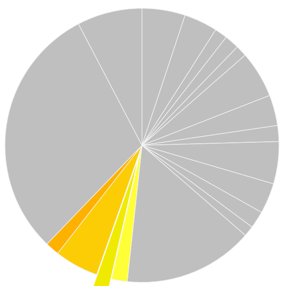
Federal Energy R&D: Carbon Storage and Utilization

BY COLIN CUNLIFF | APRIL 2019

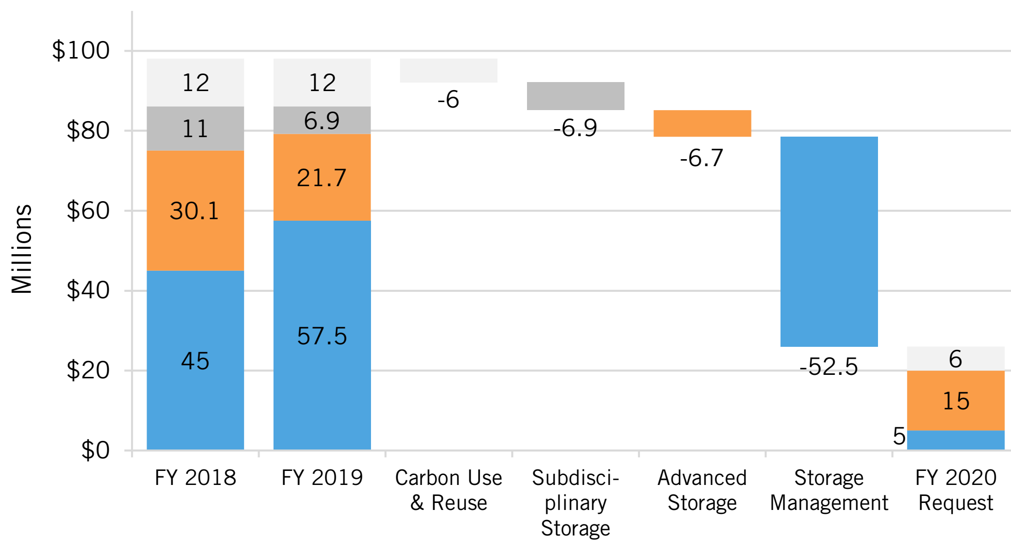
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



Carbon Storage (yellow)
Other Fossil (yellow)
Energy R&D (light gray)

The Carbon Storage and Utilization subprogram is focused on development of technologies for the safe and permanent utilization and storage of captured carbon dioxide (CO_2). It conducts research and development on 5 primary geologic storage media—saline formations, oil and natural gas reservoirs, unmineable coal seams, basalts, and organic shales—and in reservoirs across 11 geologic depositional classes.[1]

Figure 1: The FY 2020 Budget Request Would Cut Carbon Storage and Utilization R&D by 73 Percent.[2]



What's At Risk

Preliminary research suggests the United States has enough subsurface capacity to permanently sequester 1.71 trillion metric tons of CO_2, which is the equivalent of 950 years of carbon emissions from power plants at 2016 levels.[3] However, additional cost reductions, validation, safety testing, and mitigation research are necessary to realize this capacity. While the size of many subsurface storage reservoirs has been initially characterized, detailed site-specific work is required to confirm their potential. R&D is also needed to develop tools to map and simulate below-ground fractures and faults with a high degree of resolution and fidelity, devise wellbore materials that can better resist corrosion by CO_2-saturated brine, and improve the ability to monitor and mitigate the risk of induced seismicity from the injection of CO_2 underground. And large-scale, long-term demonstration projects are necessary to ensure captured carbon dioxide is safely and permanently stored.

In April 2017, the Illinois Industrial Carbon Capture and Storage project—funded jointly by DOE and private investors—began capturing CO_2 from an ethanol-production facility and storing it underground in a saline reservoir at a rate of one million metric tons of CO_2 per year. This large, first-of-a-kind demonstration project is testing and validating technologies, while concurrently endeavoring to reduce future costs.[4] In 2018, DOE selected three additional cost-shared R&D projects to identify sites that can store more than 50 million metric tons of CO_2.[5] The proposed budget would cut funding substantially for this promising effort.

Carbon Storage and Utilization R&D Activities

Funding for carbon storage and utilization R&D is spread across four activities:

- **Storage Infrastructure R&D** focuses on geologic resource characterization and small- and large-scale field projects to demonstrate permanent geologic storage; validation of injection, simulation/risk assessment, and monitoring strategies; and assessment of the probability, and subsequent mitigation, of potential seismic events. Program activities include the Carbon Storage Assurance Facility Enterprise (CarbonSAFE) initiative, which funds industry cost-shared R&D projects to characterize and develop commercial-scale (50+ million metric of CO_2) storage complexes by 2025; the Brine Extraction Storage Test (BEST), which advances strategies for managing subsurface pressure and fluid flow; and the seven Regional Carbon Sequestration Partnerships (RCSPs), which are currently testing large-scale CO_2 injection and storage technologies.[6]

- **Advanced Storage R&D** is focused on developing and validating storage monitoring, simulation, risk-assessment, and advanced wellbore technologies to detect and mitigate wellbore issues. R&D activities include developing CO_2-resistant construction materials and well-integrity technologies, plus technologies to detect and mitigate potential CO_2 leakage pathways.

- **Carbon Use & Reuse R&D** explores the beneficial reuse of CO_2, including conversion into higher-value products such as chemicals, plastics, and building materials, and accelerated curing for cement. The primary objective is to lower the near-term cost of CCUS through the creation of value-added products via the conversion of CO_2.

- **Sub-Disciplinary Storage R&D** focuses on assessment and validation of subsurface models; support for the National Risk Assessment Partnership (NRAP), with a focus on storage risk tools; and development of the Energy Data Exchange (EDX) system which supports data management and technology transfer.[7]

Key Elements of the FY 2020 Budget Proposal

- **A 91-percent reduction in Storage Infrastructure R&D,** and no funding for activities outside of “infrastructure network studies and analyses.” It is unclear whether CarbonSAFE, BEST, or the RCSPs would continue to be supported. Long-term, ongoing evaluation and monitoring of storage test sites is necessary to provide confidence that captured carbon dioxide is safely and permanently stored.

- **A 48-percent reduction in Advanced Storage R&D** (which would be merged with Sub-Disciplinary Storage R&D). Current activities in this area focus on development of monitoring, verification, accounting, and assessment (MVAA) tools for CO_2 storage; simulation and risk-assessment technologies; and advanced wellbore technologies to detect and mitigate wellbore issues from both short- and long-term exposure to CO_2. It is unclear which activities would be scaled down or discontinued under the proposed budget.

- **A 50-percent reduction in Carbon Use & Reuse R&D,** with remaining funding focused laboratory- and bench-scale activities to convert CO_2 into chemicals, fuels, and building products.

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The author wishes to thank the David M. Hart for providing input to this report. Any errors or omissions are the author's alone.

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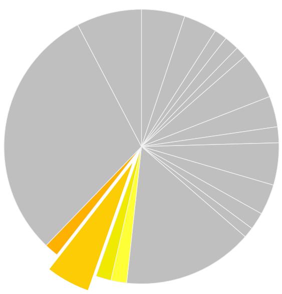
Federal Energy R&D: Advanced Coal Energy Systems

BY COLIN CUNLIFF | APRIL 2019

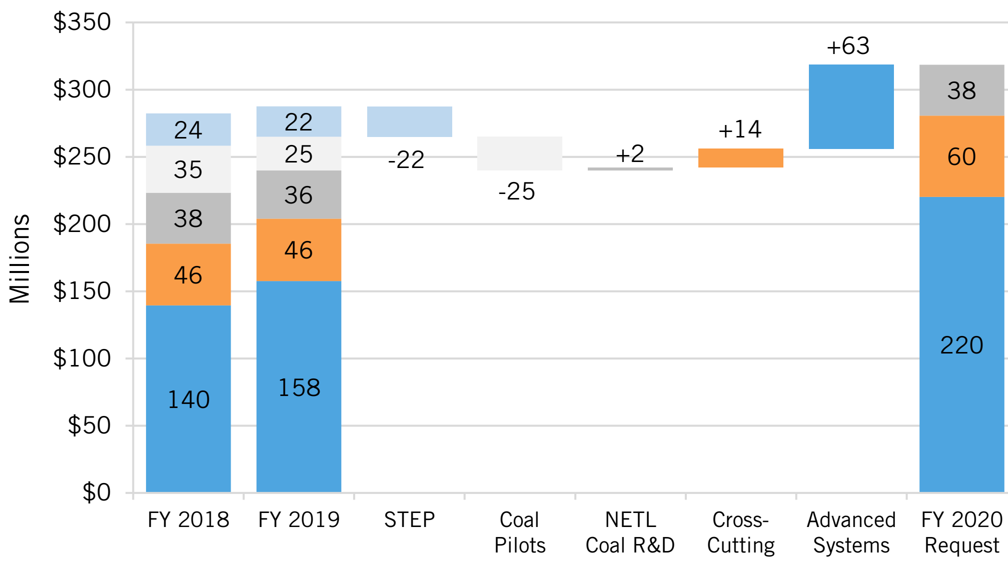
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



Adv Coal (orange)
Other Fossil (yellow)
Energy R&D (light gray)

The Department of Energy's (DOE) Advanced Coal Energy Systems R&D program focuses on improving the efficiency of coal-based power systems, developing advanced technologies such as gasification and fuel-cell systems, improving environmental mitigation of coal power, and enhancing the value of coal and coal by-products.[1]

Figure 1: The FY 2020 Budget Request Would Increase Advanced Coal Energy Systems R&D by 11 Percent.[2]



What's At Stake

Coal currently accounts for 27 percent of U.S. electricity generation and 65 percent of power-sector carbon emissions.[3] It is projected to remain an important part of the nation's energy mix for decades to come.[4] Many Advanced Coal Energy Systems R&D projects seek to minimize greenhouse gas emissions and other environmental impacts from coal-fired electricity generation, which would enable the continued use of coal in low-carbon energy system. For example, gasification systems combine coal with oxygen and steam under high pressure to produce synthesis gas, which can be used in fuel cells or combined-cycle power plants. Gasification systems are optimized for integration with pre-combustion carbon capture systems. Similarly, solid oxide fuel cells (SOFCs) convert gasified coal into electricity without combustion and with fewer emissions than conventional coal plants.[5] Additional RD&D is necessary to lower costs and sufficiently improve performance to enable commercial deployment of SOFCs and gasification systems.

The bulk of funding in DOE's Advanced Coal Energy Systems programs supports activities to improve the efficiency of existing coal plants or to design and build new high-efficiency coal plants, which would improve the economics of coal-fired electricity generation. But without integration with carbon capture, utilization, and storage (CCUS) technologies, efficiency improvements alone will not be sufficient to achieve deep emissions reductions from coal-fired power plants.

Advanced Coal Energy Systems Subprograms

Advanced Coal Energy Systems R&D is spread across five subprograms:[6]

- **Advanced Energy Systems** focuses on improving the efficiency of coal-based power systems and supports research across seven areas: gasification, which converts coal into synthesis gas, chemicals, hydrogen, and liquid fuels (and complements pre-combustion carbon capture R&D); solid oxide fuel cells, which can convert synthesis gas and other fuels into electricity without combustion or emissions; advanced turbines; advanced sensors and controls; power-generation efficiency; advanced energy materials; and coal processing.

- **Cross-cutting Research** serves as a bridge between basic and applied research by targeting the concepts with the greatest potential for transformational breakthroughs. Current research focuses on these primary activities: improved water management in power plant operations; recovery of rare earth elements as a byproduct of coal production and use; and modeling, simulation, and analysis of environmental and regulatory impacts.

- **Supercritical Transformational Electric Power (STEP)** is a 10 MW pilot-scale demonstration of a Brayton cycle energy conversion system, which uses supercritical CO_2 rather than the traditional steam/water Rankine cycle to convert heat to electricity. Supercritical CO_2 cycles have higher thermal efficiencies and have applications for nuclear, gas, and concentrating-solar as well as coal power plants.[7]

- **Transformational Coal Pilots** provides funding for the design, construction, and operational costs of two large-scale pilot projects for transformational coal technologies, including pressurized oxygen combustion and chemical looping, and improvements in carbon capture systems.[8]

- **NETL Coal R&D** funds all NETL in-house research efforts, including the Fossil Energy Roadmap and the NETL Science & Technology competency assessments.

Key Elements of the FY 2020 Budget Proposal[9]

- **Continues the administration's Coal FIRST (Flexible, Innovative, Resilient, Small, Transformative) initiative to advance new coal power plant designs** that are small (50 to 350 MW), efficient (40 percent or more thermal efficiency), capable of ramping, and have emissions less than or equal to natural gas plants.

- **A 40-percent increase in Advanced Energy Systems**, with $70 million in new funding for the new Coal FIRST initiative for new first-of-a-kind coal generation technologies, and $30 million to improve the performance of existing coal plants. Funding for advanced sensors and controls and advanced energy materials would also receive increases. Funding for turbines that can withstand higher temperatures and pressures, gasification systems, and coal processing would be reduced; and solid oxide fuel cell R&D would be cut by 90 percent.

- **A 30-percent increase in Cross-cutting Research,** including increases for rare earth element extraction and separation from coal byproducts; waste-water treatment and other water management R&D; modeling, simulation, and analysis to improve operational efficiency; university training and research; and funding for new intra-agency initiatives in harsh environment materials and advanced energy storage.

- **A discontinuation of funding for the Transformational Coal Pilots program.** Approximately $15 million in prior year funding will be used to select five Phase II (design) awards in August 2019, and the balance of prior year funding will be used for at least one Phase III (construction/operation) award.

- **A discontinuation of funding for STEP,** as prior year balances have fully funded the pilot STEP project, now under construction in San Antonio, and the administration has not announced any plans follow-on work.

- **A 6-percent boost to NETL Coal R&D** in the areas of systems engineering and analysis, structural materials, and geological and environmental systems.

ENDNOTES

1. DOE is proposing to restructure its R&D programs within the CCS and Power Systems account to a new structure that "improves the alignment of the budget structure to the research focus areas…" Here, the term "Advanced Coal Energy Systems" refers to the programs in the new budget structure, minus the carbon capture, utilization, and storage (CCUS) programs. DOE, "FY 2020 Congressional Budget Justification," Volume 3 Part 1, 421-459, (DOE Chief Financial Officer, DOE/CF-0152, March 2019), https://www.energy.gov/sites/prod/files/2019/03/f61/doe-fy2020-budget-volume-3-part-1_0.pdf.
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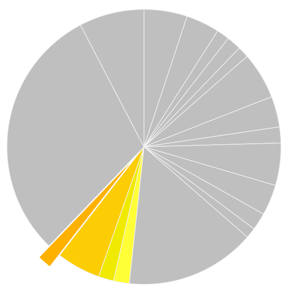


Oil & Gas (orange)
Other Fossil (yellow)
Energy R&D (light gray)

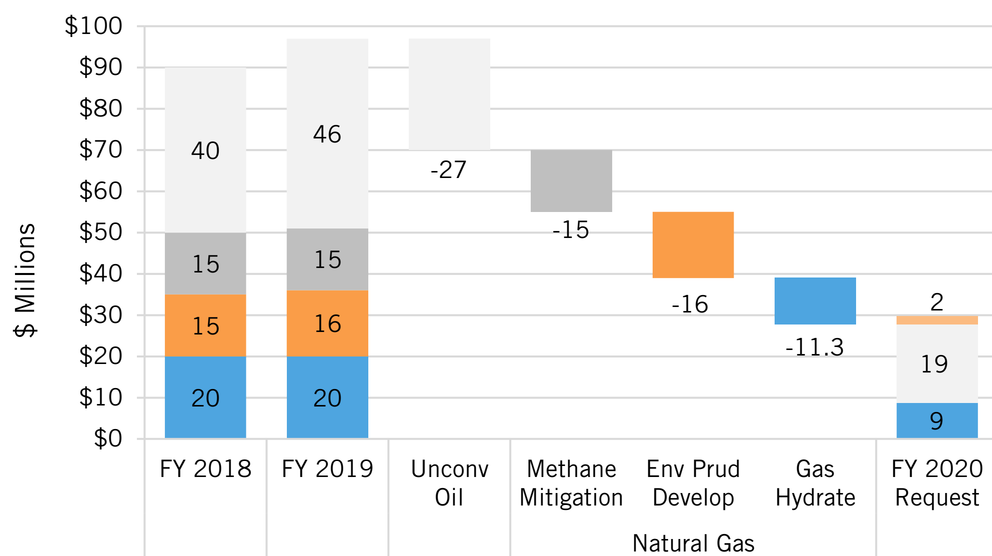
Federal Energy R&D: Oil & Gas

BY COLIN CUNLIFF | APRIL 2019

This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.

The Department of Energy's (DOE) oil and natural gas program supports R&D to ensure domestic production, transmission, storage, and distribution of oil and natural gas remain safe, secure, and environmentally prudent. A key focus of this program has been to improve the safety and mitigate the environmental impacts of oil and natural-gas energy systems. The program has explored the connection between hydraulic fracturing and induced seismicity, while also seeking to reduce fugitive methane emissions. In addition, it has funded R&D to reduce the amount of water used in oil and gas production, and to develop technologies to treat brackish water that is co-produced with oil and gas. The program also focuses on the development of new oil and gas resources, including methane hydrates and unconventional oil.[1]

Figure 1: The FY 2020 Budget Request Would Reduce Oil and Gas R&D by 69 Percent.[2]



What's At Risk

Domestic production from unconventional reservoirs has enabled the United States to become the world's largest producer of oil and gas over the last few years, keeping energy prices low, and decreasing reliance on imported crude oil. DOE's R&D activities focus on improving the efficiency of natural gas infrastructures—including pipelines and storage facilities—to reduce natural gas leaks and better conserve domestic energy resources, as well as address high-priority challenges to the safe and prudent development of unconventional oil and gas resources. Additional R&D activities include treating and managing co-produced water, characterizing and minimizing induced seismic risk, and reducing surface footprints on well pad sites and surrounding areas.[3] Reduced funding could inhibit progress toward key public health, safety, and environmental goals.

Other programs seek to expand access to domestic oil and gas resources. Current technology allows for recovery of only 7 to 10 percent of the oil found in such unconventional reservoirs, but R&D on subsurface flow mechanics seeks to improve recoverability factors. R&D to characterize and evaluate domestic sources of methane hydrate deposits could also lead to large new sources of domestic natural gas in such places as Alaska and the Gulf of Mexico.[4]

Oil & Gas R&D Activities

R&D in oil and natural gas is spread among four activities:[5]

- **Unconventional Fossil Energy from Petroleum R&D** supports the development of domestic production from unconventional reservoirs, which requires complicated engineering measures, such as hydraulic fracturing and directional drilling, to improve access and enable commercial production.
- **Methane Emissions Quantification and Mitigation** focuses on technologies that quantify and reduce methane leaks and vented emissions from natural gas systems. Methane, the main component of natural gas, is a powerful greenhouse gas that, on a pound-for-pound basis, is about 30 times more effective at trapping heat than carbon dioxide, although its atmospheric residence time is much shorter.[6] Reducing methane emissions would have the dual effect of improving the environmental performance of natural gas systems and enhancing stewardship of domestic gas resources.
- **Environmentally Prudent Development** conducts research on induced seismicity and wellbore integrity, as well as into water quality, water availability, air quality, and environmental impacts of oil and gas resource development.
- **Gas Hydrates R&D** aims to develop technologies that will enable natural gas production from domestic and arctic offshore methane hydrate deposits. Gas hydrates are methane molecules trapped in ice that turn into natural gas and water when heated or depressurized.

Key Elements of the FY 2020 Budget Proposal

- **Elimination of the Methane Emissions Quantification and Mitigation programs,** which would stall domestic efforts to reduce methane leaks and fugitive emissions from oil and natural gas systems. Methane, the main component of natural gas, is the second-largest driver of climate change (behind only carbon dioxide), accounting for more than 10 percent of annual U.S. greenhouse gas emissions.[7] Oil and gas systems together account for the largest share of domestic methane emissions, with the lost methane valued at an estimated $2 billion.[8]

These R&D programs to reduce fugitive emissions and leaks from oil and gas systems therefore serve multiple purposes: They conserve domestic energy resources; reduce waste and inefficiencies in oil and gas systems, which keeps costs low for consumers; provide value to oil and gas producers by ensuring that more gas makes its way to the consumer; and reduce the greenhouse gas emissions that cause climate change.

- **Elimination of the Environmentally Prudent Development program,** which would hinder efforts to mitigate the environmental impacts of natural gas production.
- **Creation of a new $2 million Natural Gas Infrastructure Research program** (light orange in the FY 2020 Request bar in figure 1), with research to focus on advanced materials and sensors for midstream gas infrastructure and conversion technologies for stranded and vented gas. This funding level is tiny in comparison to the other gas programs and does not provide an adequate substitute for the methane emissions quantification and mitigation programs or the environmentally prudent development program.
- **A 56-percent reduction in Gas Hydrates research** following the completion in FY 2019 of the stratigraphic well on the North Slope of Alaska.
- **A 59-percent reduction in Unconventional Oil R&D,** due to a focus on current field laboratory projects, with no additional field test sites budgeted in FY 2020.

ENDNOTES

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2. The Emissions Mitigation from Midstream Infrastructure ($10 million in FY 2019) and Emissions Quantification from Natural Gas Infrastructure ($5 million in FY 2019) programs are grouped in the figure under the category "Methane Mitigation." The proposed budget would terminate the methane quantification and mitigation programs and the Environmentally Prudent Development program and create a new Natural Gas Infrastructure Research program ($2 million in FY 2020), shown in light orange on the FY 2020 Request column. DOE, "FY 2020 Congressional Budget Justification," Volume 3 Part 1, 461-472, (DOE Chief Financial Officers, DOE/CF-0152, March 2019), https://www.energy.gov/sites/prod/files/2019/03/f61/doe-fy2020-budget-volume-3-part-1_0.pdf.
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The author wishes to thank the David M. Hart for providing input to this report. Any errors or omissions are the author’s alone.

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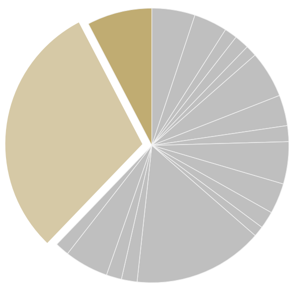
BY COLIN CUNLIFF | APRIL 2019

Federal Energy RD&D: Basic Energy Sciences

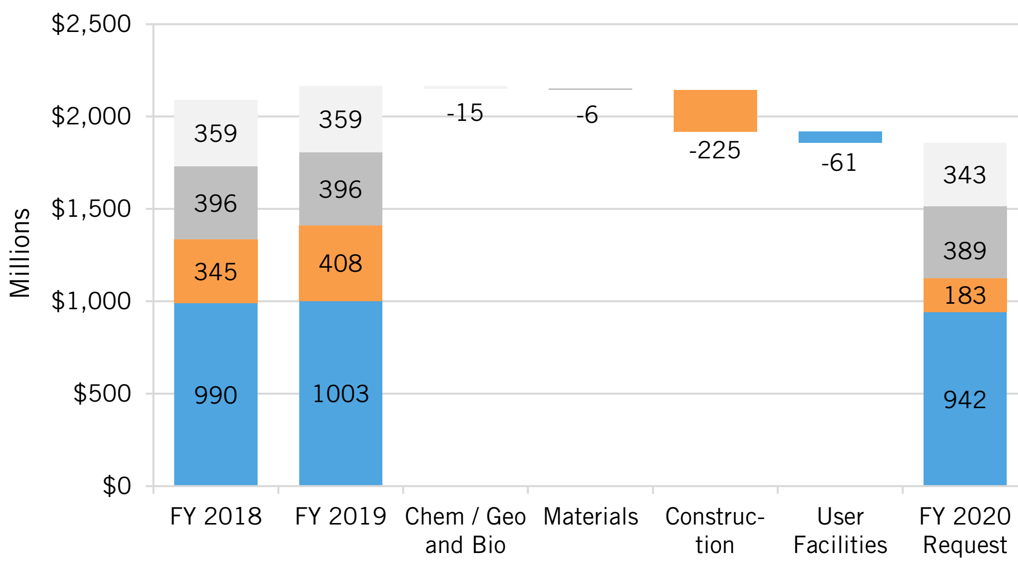
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



Basic Energy Science (light brown)
Fusion (brown)
Energy R&D (light gray)

Basic Energy Sciences (BES) support fundamental research into understanding and controlling matter and energy, thereby helping to build the foundation for new energy technologies. BES research—in condensed matter and materials physics, chemistry, geosciences, and aspects of biosciences—touches virtually every important facet of energy production, transmission, storage, and waste mitigation. BES also operates open-access scientific "user facilities" that enable researchers from private industry, national laboratories, and universities to use advanced instruments and tools that are too expensive for a single university lab or private company to own and operate.[1]

Figure 1: The FY 2020 budget request would cut basic energy sciences R&D by 14 percent.[2]



What's At Risk

Research in basic energy sciences is a key component of the energy innovation ecosystem. In 2018, the BES Advisory Committee produced a retrospective report, "A Remarkable Return on Investment in Fundamental Research," identifying some of the groundbreaking discoveries made as a result of BES funding that—years, and often decades, later—have resulted in the commercialization of new technologies that shape the way we produce and consume energy.[3] The National Academy of Sciences has called for a doubling of basic science research, including basic energy sciences, as a means of addressing challenges to U.S. competitiveness.[4]

BES supports 46 Energy Frontier Research Centers (EFRCs), which are partnerships among universities, national laboratories, and industry that integrate the talents and insights of leading scientists and engineers to confront critical energy challenges across sectors. BES also houses two energy innovation hubs: the Fuels from Sunlight Hub, which seeks to generate fuels directly from sunlight, carbon dioxide, and water in a manner similar to natural photosynthesis; and the Batteries and Energy Storage Hub, which researches nanoscale phenomena to develop next-generation, beyond-lithium-ion-energy storage systems. BES's 12 user facilities provide nearly 16,000 industry, government, and academic researchers access to advanced research capabilities, including x-ray lasers, accelerators, neutron sources, and tools to probe matter on the nano-scale.[5]

Basic Energy Sciences R&D Activities

R&D in basic energy is distributed across three subprograms:[6]

- **Materials Science and Engineering** supports research on materials synthesis, behavior, and performance for a wide range of energy-generation and end-use challenges, with a focus on the origin of macroscopic-material behaviors; their fundamental connections to atomic, molecular, and electronic structures; and their evolution as materials move from nanoscale building blocks to mesoscale systems.

- **Chemical Sciences, Geosciences, and Biosciences** supports research on chemical reactivity and energy conversion, which is the foundation for energy-relevant chemical processes—such as catalysis, synthesis, and light-induced chemical transformation—to achieve a fully predictive understanding of complex chemical, geochemical, and biochemical systems at the same level of detail as simple molecular systems.

- **Scientific User Facilities** supports the operation of 12 user facilities—five light sources, two neutron scattering facilities, and five nanoscale science research centers—that provide thousands of researchers from universities, industry, and government laboratories unique tools to advance a wide range of science research. These user facilities are operated on an open-access, competitive merit review basis, enabling public and private researchers from every discipline to take advantage of the facilities' unique capabilities and instrumentation.

- **Construction** supports the construction of new user facilities and upgrades to existing facilities, including the Linac Coherent Light Source-II, which will be the world's most powerful x-ray free electron laser.

Key Elements of the FY 2020 Budget Proposal[7]

- **Funding the BES User Facilities at "87 percent optimum,"** which means the user facilities would only be operated for 87 percent of the total potential operating time. 1,710 fewer researchers would be able to use the BES User Facilities.

- **An 18 percent boost to funding for EFRCs,** with the additional funding going to new EFRCs in microelectronics and quantum information systems.

- **Flat funding for the Batteries and Energy Storage innovation hub**, which was recently extended for a second five-year term.

- **A 33 percent boost in funding for the Fuels from Sunlight innovation hub.** After completion of a second five-year term of the hub, led jointly by Caltech and LBNL, BES will hold an open competition to solicit proposal for a new hub.

- **A 62 percent cut to the Established Program to Stimulate Competitive Research (EPSCoR)**, a program to advance research capabilities in states and territories with historically lower levels of Federal research funding.

- **Near-flat funding for Materials Science and Engineering Research**. Scattering and instrumentation sciences research would get a $6 million cut; materials discovery research would get a $5.5 million cut; computational materials sciences would receive flat funding; and condensed matter research would get an $8 million boost.

- **Near-flat funding for Chemical Sciences, Geosciences, and Biosciences**. Research in fundamental interactions would be cut by $5 million; chemical transformations by $14 million; and photochemistry and biochemistry by $12 million. Computational chemical sciences would receive flat funding.

ENDNOTES

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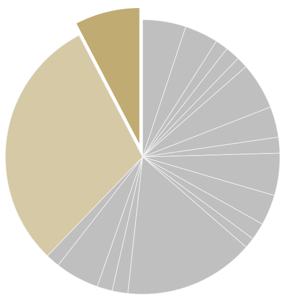
Federal Energy R&D: Fusion Energy Sciences

BY COLIN CUNLIFF | APRIL 2019

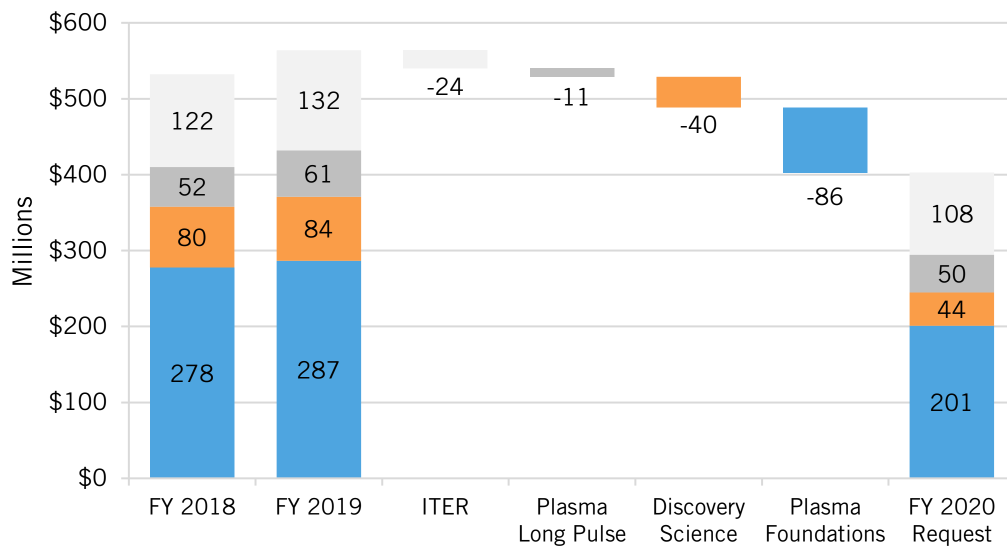
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



Fusion Energy (brown)
Basic Energy Science (brown)
Energy R&D (light gray)

The mission of the Fusion Energy Sciences (FES) program is to help build the scientific foundation needed to develop a fusion energy source by expanding the fundamental understanding of the physics behind plasmas (i.e., matter at very high temperatures and densities).[1] Comprising 99 percent of the visible universe, plasmas are at the heart of the fusion process that powers the stars. The promise of fusion—an energy system that could generate massive amounts of power, using fuel obtained from seawater and earth-abundant materials, with very little pollution—is enormous.

Figure 1: The FY 2020 budget request would cut fusion R&D by 29 percent.[2]



What's At Risk

Fusion RD&D has the potential to contribute to U.S. energy security by making available a robust clean energy technology that relies on widely available and virtually inexhaustible fuel sources. However, the technological advances needed to realize safe, low-cost fusion are still nascent, so basic research into plasma physics—including plasma confinement and plasma-materials interactions—remains essential to advancing toward the goal of fusion energy. Reductions in funding for this program could stall advances in fusion science, while threatening the United States' leadership in this important area.

Because its science is so wide-ranging, plasma research could spin off a number of applications for other technologies. Advances developed in the quest for fusion energy have already led to the creation of other technologies that provide considerable economic and societal impact, including applications in lighting, semiconductor manufacturing, medical and health science and technology, materials, and waste management.[3] Robust plasma-research funding is therefore necessary to prevent the United States from losing out on future benefits in these and other industries.

Fusion Energy Sciences R&D Activities

R&D in fusion energy is distributed across four subprograms:[4]

- **Burning Plasma Science: Foundations** advances the predictive understanding of plasma confinement, dynamics, and interactions with surrounding materials—and conducts research in advanced tokamak and spherical-tokamak science, as well as small-scale magnetic confinement experiments.
- **Burning Plasma Science: Long Pulse** explores new scientific regimes using long-duration superconducting international machines, and addresses the development of materials and technologies required to withstand and sustain burning plasma.
- **Discovery Plasma Science** explores the fundamental properties and complex behavior of matter in the plasma state to improve the understanding required to control and manipulate plasmas for a broad range of applications.
- **International Thermonuclear Experimental Reactor (ITER)** is an ambitious international collaboration among seven governments (China, the European Union, India, Japan, the Republic of Korea, the Russian Federation, and the United States) to demonstrate the scientific and technological feasibility of fusion power for electricity generation.

Key Elements of the FY 2020 Budget Proposal

- **A 30-percent reduction in Basic Plasma Science: Foundations**, including a $37 million cut to research and operations at DIII-D, the largest magnetic fusion user facility in the United States; and a $27.5 million cut to research and operations at the National Spherical Torus Experiment Upgrade (NSTX-U), the most powerful spherical tokamak user facility in the world.
- **An 18-percent reduction in Basic Plasma Science: Long Pulse**, including reductions in long-pulse tokamaks, as well as reductions in the fusion nuclear science and materials research that seeks to understand how plasmas interact with the materials that might be used in future fusion facilities.
- **A 48-percent reduction in Discovery Plasma Science,** including elimination of research in exploratory magnetized plasmas—which is necessary to advance innovative solutions and capabilities for the creation, control, and manipulation of magnetically confined plasmas for terrestrial and space applications; reductions in general plasma science, which explores low-temperature plasma science and

engineering; and reductions in high energy density plasma science, which explores the behavior of matter at extreme conditions of temperature, density, and pressure.

- **A 19-percent reduced contribution to the International Thermonuclear Experimental Reactor (ITER)**. As a member of ITER, the United States has committed to provide 9 of the construction costs in return for full access to all ITER technology and scientific data, which represents a significant opportunity for U.S. universities, laboratories, and industries to both design and construct parts, and propose and conduct experiments.[5]

ENDNOTES

1. DOE, "FY 2020 Congressional Budget Justification," Volume 4, DOE/CF-0154 (Washington, D.C.: DOE Chief Financial Officer, March 2019), 157-181, https://www.energy.gov/sites/prod/files/2019/03/f61/doe-fy2020-budget-volume-4.pdf.
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