INFORMATION TECHNOLOGY & INNOVATION FOUNDATION

Energy Innovation in the FY 2021 Budget: Congress Should Lead

BY COLIN CUNLIFF | MARCH 2020

Congress should make energy innovation a national imperative, and at least double U.S. investment in clean energy RD&D by 2025.

As it has in the past three budget cycles, the Trump administration has once again proposed massive cuts to energy research, development, and demonstration (RD&D), placing the administration's budget request in tension with bipartisan congressional efforts to reinvigorate the national energy innovation system.[1] Fortunately, Congress has soundly rejected the administration's previous budget proposals in this area, instead putting forward a positive vision for American innovation that invests in a future of clean, reliable, low-cost energy. Congress has also produced a strong slate of bipartisan, bicameral authorizing bills that would accelerate innovation if backed by significant new funding commensurate with the challenge.[2] Congress should keep up the momentum of the past three fiscal years and continue to elevate clean energy innovation as a national priority.

The administration's latest budget request would slash federal investments in the Department of Energy's (DOE) applied energy programs—including energy efficiency, renewable energy, sustainable transportation, fossil energy, nuclear energy, and grid modernization—by more than 44 percent, from $5.4 billion in FY 2020 to $3.0 billion in FY 2021. Popular and effective initiatives including the Advanced Research Projects Agency-Energy (ARPA-E), Title XVII loan guarantee program, and advanced vehicles manufacturing loan program would be eliminated. Even the basic energy-related research within the DOE Office of Science (SC)—which includes programs in fusion, bioenergy, and basic energy sciences, and falls squarely within the definition of "early stage research" the administration claims to support—would receive an 18 percent cut, from $3 billion in FY 2020 to $2.5 billion.[3] If enacted, this budget would impose the largest single-year cut to energy RD&D investments in the history of the department, bringing federal energy RD&D down to its lowest level since 2007.

Even more troubling, the proposed cuts come amid signs of a struggling domestic clean energy industry that is at risk of falling behind international competitors. China has ramped up investments in energy RD&D and now invests far more than the United States in key technologies, including solar energy, lithium-ion batteries, advanced nuclear, carbon capture, and electric vehicles. Europe is outstripping the United States in offshore wind. And U.S. companies account for a declining share of new cleantech patents, indicating the United States is falling behind in innovation.[4]

Congress has wisely taken note of these developments, providing significant boosts to federal clean energy RD&D investment in each of the last three budget cycles and using its authorizing powers to address key innovation challenges.[5] Support for more aggressive federal investments spans the political spectrum from conservative House Republicans, who have begun to tout innovation to address climate change, to progressive Democrats, who acknowledge that innovation will be needed to fully eliminate carbon emissions.[6]

The Trump administration has recognized the need to invest in innovation in order to maintain international leadership in certain emerging technologies. Its Industries of the Future initiative proposes to double federal investment in artificial intelligence, quantum information sciences (QIS), and other areas.[7] However, the administration's failure to include clean energy technologies on this list—in concert with its determination to double down on its support of unabated fossil fuels—represents a huge missed opportunity that would radically diminish America's role in the coming global transition.

Congress should reject the president's budget request and continue to elevate innovation in clean energy as a national priority in 2021. The Information Technology and Innovation Foundation (ITIF) recommends that Congress:

- Provide robust investment in clean energy innovation during the FY 2021 appropriation cycle, while laying the groundwork for an aggressive multiyear increase, similar to the five-year doubling for medical research at the National Institutes of Health (NIH) in 1998–2003;[8]
- Grow the ARPA-E budget to $1 billion by 2025;[9]
- Initiate new programs that address innovation gaps, particularly for manufacturing and harder-to-abate sources of carbon emissions in the industrial and transportation sectors, as well as for technologies to remove carbon directly from the air;[10] and
- Build a robust, diverse portfolio of large-scale energy technology demonstration projects.[11]

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 DOE's current energy RD&D portfolio, what is at risk in the administration's FY 2021 budget request, and next steps in the appropriations process. Companion to this report is a series of short, 4-page briefs on the 19 science and technology program offices that make up DOE's energy innovation portfolio, 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

Both public 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 nearly 70 percent of total research and development (R&D) spending across all industries.[12] However, industrial innovation is by nature incremental and focused on relatively short-term payoffs.[13]

The energy industry invests a very small share of its revenues, just 0.5 percent, in R&D.[14] That is far less than the 14.2 percent R&D-to-revenue ratio found in pharmaceuticals, 11.3 percent in computers and electronics, 7.5 percent in aerospace and defense, and even 3.2 percent in autos.[15] The American Energy Innovation Council (AEIC), a group of the nation's most 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.[16] Even venture capital 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.[17]

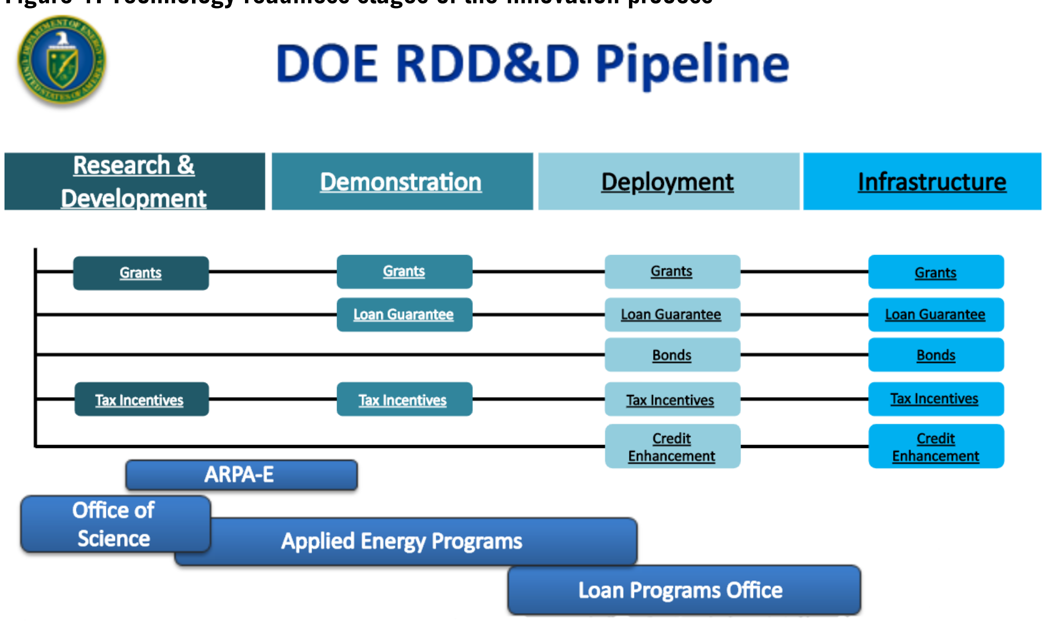
In addition, because energy is valued as a commodity—i.e., there is no tangible difference in the electricity that comes from a coal plant versus a wind farm—emerging energy technologies frequently cannot distinguish themselves from incumbent technologies and must therefore compete on price and performance from the moment they enter the market.[18] Electric utilities are often legally mandated to keep prices low, and are prohibited from investing in new technologies.[19]

The federal government is uniquely suited to address these barriers, making high-risk, long-term investments the private sector is simply unwilling to fund. The shale-gas revolution provides a case in point: Federal support for the development of advanced drill bits, directional drilling, and shale resource characterization in the late 1970s ultimately led to the shale-gas revolution in the mid-2000s, driving down energy costs for millions of Americans and enabling the United States to become a net exporter of natural gas.

But the path from discovery of domestic shale resources to widespread shale-gas production entailed more risk than any single company could bear, and required a range of policies working in concert to bring shale gas to market. The federal government funded fundamental research, countenanced and funded industry-wide collaboration in applied R&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 production tax credit that provided a complementary pull. 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, shale gas production has grown dramatically, to more than 70 percent of domestic gas production.[20]

As the shale-gas example illustrates, accelerating energy innovation requires a range of policies acting together across the innovation spectrum (see figure 1). For technologies that are far from commercialized, basic and applied research and technology development are necessary to improve the performance and drive down the cost of emerging technologies to the point entrepreneurs and corporate R&D units jump in. As technologies mature, successful demonstration at commercial scale is required to establish cost, reliability, and performance characteristics, and provide confidence to more risk-averse investors and the public that the technology works as intended at a manageable cost. 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 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.

Figure 1: Technology readiness stages of the innovation process[21]



DOE's key role in bringing shale-gas technology to maturity is just one example in an impressive list of accomplishments. Federal investments by DOE's predecessor agencies were responsible for launching the private nuclear industry, which now contributes 20 percent of U.S. electricity. DOE helped develop low-cost flue-gas desulfurization scrubbers for power plants, which made the United States into a global leader in pollution control technologies, while also lowering energy costs and improving air quality for all Americans. And new methods for producing quantum dots—which have applications in high-efficiency TV screens, solid-state lighting, and quantum computing—were first developed in DOE laboratories. In each of these cases, the road from discovery to deployment took decades, required government investment to develop and "de-risk" the inventions, and entailed public and private partners working together to bring them to market.

AEIC summed things up in its 2020 report "Energy Innovation: Supporting the Full Innovation Lifecycle":[22]

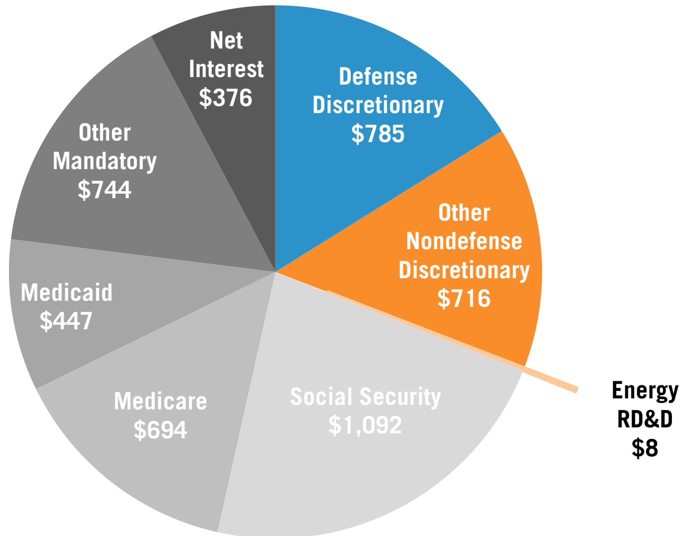
> [T]he U.S. government has long been a driving force in generating scientific breakthroughs, as well as a key partner to industry in funding technologies that have become central to modern life and the productive functioning of an advanced economy. This isn't to diminish the importance of industry research, but rather to acknowledge innovative technologies often emerge from the cross-pollination of ideas supported by both government and industry. … the public and private sector have unique strengths and differences in risk tolerance, and each plays a crucial and interdependent role across the innovation cycle.

FEDERAL ENERGY RD&D: GENERATING HUGE RETURNS ON A MODEST INVESTMENT

Out of a total budget of nearly $4.8 trillion, the federal government funded DOE at $38.6 billion in FY 2020. But only $8 billion—about 21 percent of DOE's budget and less than 0.2 percent of the federal budget (see figure 2)—supports energy innovation, with defense, environmental cleanup, and non-energy-related basic science research accounting for the rest. Federal investment in energy RD&D is an even smaller share of the U.S. economy, only about 0.04 percent of U.S. gross domestic product (GDP).

DOE was created in the late 1970s—a time when energy demand was increasing rapidly, energy prices were high and rising, and the Organization of the Petroleum Exporting Countries (OPEC) was flexing its muscles in global oil markets. Energy innovation and the development of domestic clean energy resources were viewed as matters of economic and national security. In 1978, Congress invested more than $10.5 billion (in 2020 dollars) in energy RD&D, or 0.14 percent of GDP. Had federal investment kept pace with growth in the economy, DOE's RD&D budget today would be $32 billion, on par with other national priorities such as health research.[23]

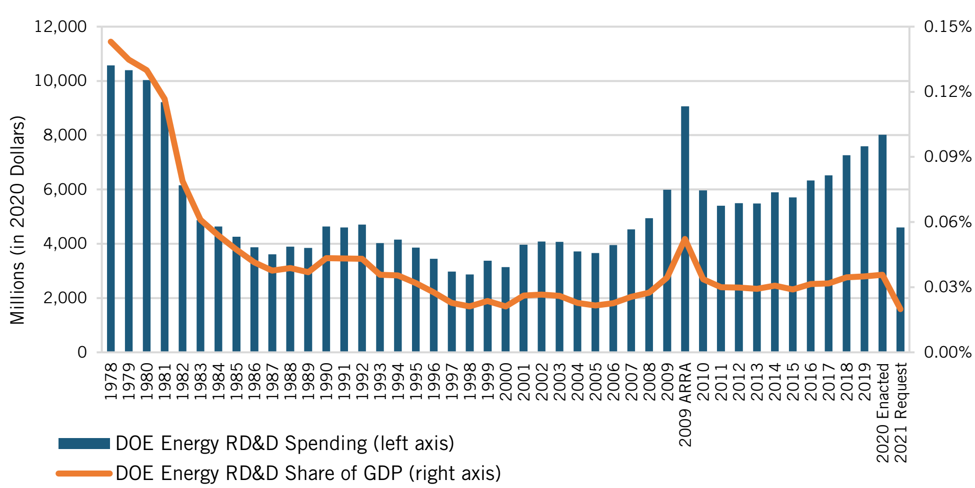
Figure 2: Federal energy research as a share of total outlays in FY 2020 (in billions)[24]



U.S. investment in energy research has declined from 0.14 percent of GDP in 1978 to 0.04 percent in 2019. Had investment kept pace with the economy, DOE's RD&D budget today would be $32 billion.

The threat posed by climate change is more severe than the energy shortage crises of the late 1970s, but the government is investing far less in energy innovation to meet this challenge. As energy prices fell in the 1980s, energy innovation receded as a national priority, with funding levels hovering below $4 billion for most of the mid-1980s through the early 2000s. During the George W. Bush administration, Congress began increasing funding in response to higher energy prices and reports that the United States risked falling behind other nations in clean energy.[25] And as part of Mission Innovation—an international agreement launched in tandem with the Paris Climate Agreement to accelerate clean energy innovation—the United States committed to doubling clean energy RD&D by 2021, providing additional impetus for congressional appropriators.[26] Congress has increased budgets for DOE's energy programs for 11 of the last 15 years, but annual appropriations have consistently fallen short of doubling targets, and funding has not yet returned to its 1978 level (see figure 3).

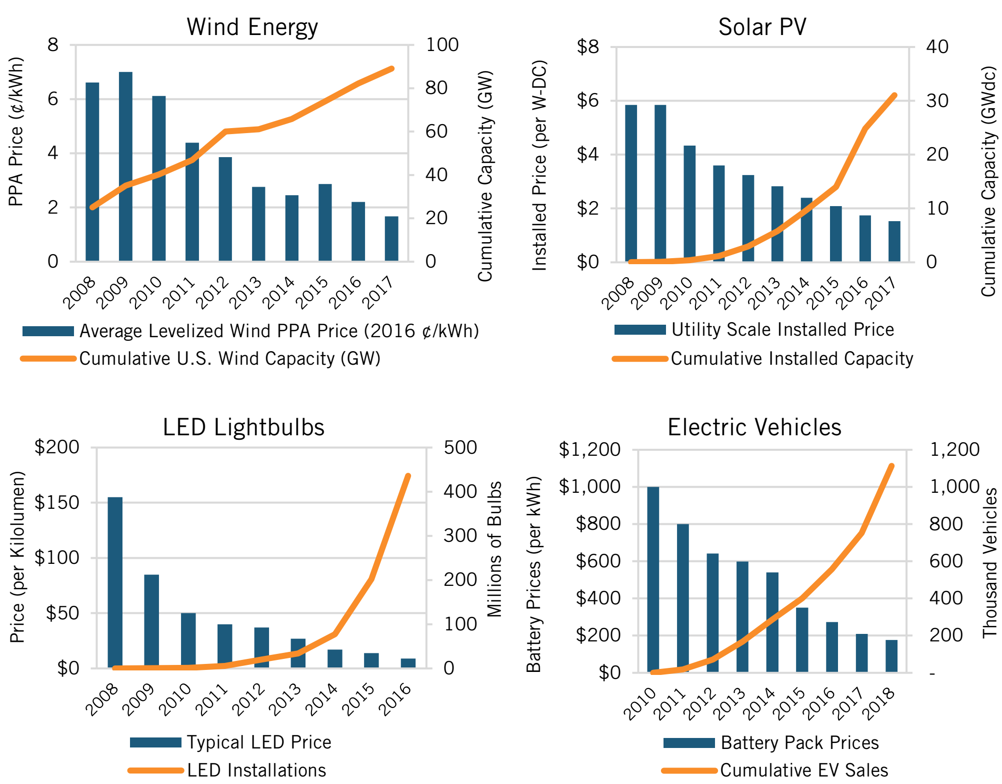
Figure 3: U.S. DOE RD&D spending, FY 1978 through FY 2021 request[27]



Despite a comparatively small investment, federal energy RD&D has delivered big returns for the American public. Decades of federal investment in solar and wind power, lithium-ion batteries, and efficient LED lightbulbs, for instance, have led to cost reductions ranging from 55 to 94 percent since 2008, leading to impressive growth in adoption, and generating huge benefits for taxpayers (see figure 4).[28] An external review of energy efficiency and renewable energy RD&D at DOE found that a total taxpayer investment of $12 billion between 1975 and 2015 yielded more than $388 billion in net economic benefits, a remarkable return of over $32 for every federal dollar invested.[29]

Similarly, a review of the Building Technologies Office (BTO)—which accounts for just 4 percent of DOE's applied energy budget—found that federal investments between 2010 and 2015 culminated in the successful commercialization of 27 products, including energy-efficient water heaters, solid-state lighting, and energy-saving windows.[30] 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 a benefit-to-cost ratio of more than 20 to 1.[31]

Figure 4: Cost reductions and capacity buildouts in four key clean technologies[32]



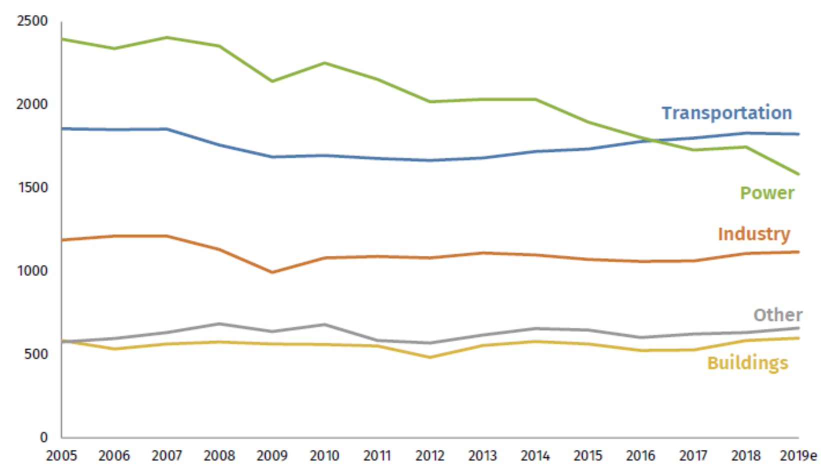
DOE research has also helped reduce the environmental impacts of fossil fuel consumption. DOE partnerships with major engine manufacturers to develop more-efficient diesel engines saved the U.S. trucking industry 17.6 billion gallons of diesel fuel over the 12 years between 1995 and 2007, which translated into $34.5 billion in reduced fuel expenditures and $35.7 billion in health and environmental benefits from lower pollution.[33] DOE leadership in carbon capture technologies led to successful first-of-a-kind demonstrations of carbon capture at a fertilizer production facility (Port Arthur, in 2013), a corn ethanol refinery (ADM, in 2017), and a coal power plant (Petra Nova, in 2017).[34] And DOE has issued a conditional loan guarantee of up to $2 billion to build the world's first clean methanol facility with carbon capture in Lake Charles, Louisiana, with construction slated to begin in mid-2020.[35]

DOE is now preparing to launch new programs to address new challenges. The Office of Fossil Energy (FE) is beginning to research technologies that can remove carbon dioxide directly from the atmosphere. The Geothermal Technologies Office is building a field laboratory in Milford, Utah, to research systems that may ultimately provide clean baseload power.[36] The Nuclear Energy (NE) office is planning a versatile test reactor user facility in Idaho to jump-start innovation in advanced non-light-water nuclear reactors.[37] The Solar Energy program just released a new funding opportunity announcement that aims to demonstrate concentrating solar power with a supercritical Brayton cycle, improve efficiencies of solar photovoltaics (PVs), and develop innovative solar PV manufacturing technologies and processes.[38] Such initiatives are promising, but are just the beginning of what should be long-term, multiyear investments. Many of them would receive reduced funding or be eliminated under the administration's proposal.

Every $1 invested in energy efficiency and renewable energy RD&D between 1975 and 2015 returned an average of $32 in economic benefits to the American taxpayer.

But even at current funding levels, DOE's energy programs fall far short of accelerating the pace of innovation sufficiently to meet the climate challenge. While emissions in the electricity sector have declined due to cheap natural gas and subsidized renewables, emissions from the industrial sector have barely budged in recent years, and emissions from transportation and buildings sectors are increasing (see figure 3). RD&D programs that would tackle emissions in these large and growing hard-to-decarbonize sectors comprise a disproportionately small portion of DOE's portfolio. For example, the industrial sector accounts for 22 percent of direct greenhouse gas (GHG) emissions but only 6 percent of DOE's overall energy RD&D budget.[39]

Figure 5: Net U.S. GHG emissions by sector[40]



Source: Rhodium Climate Service

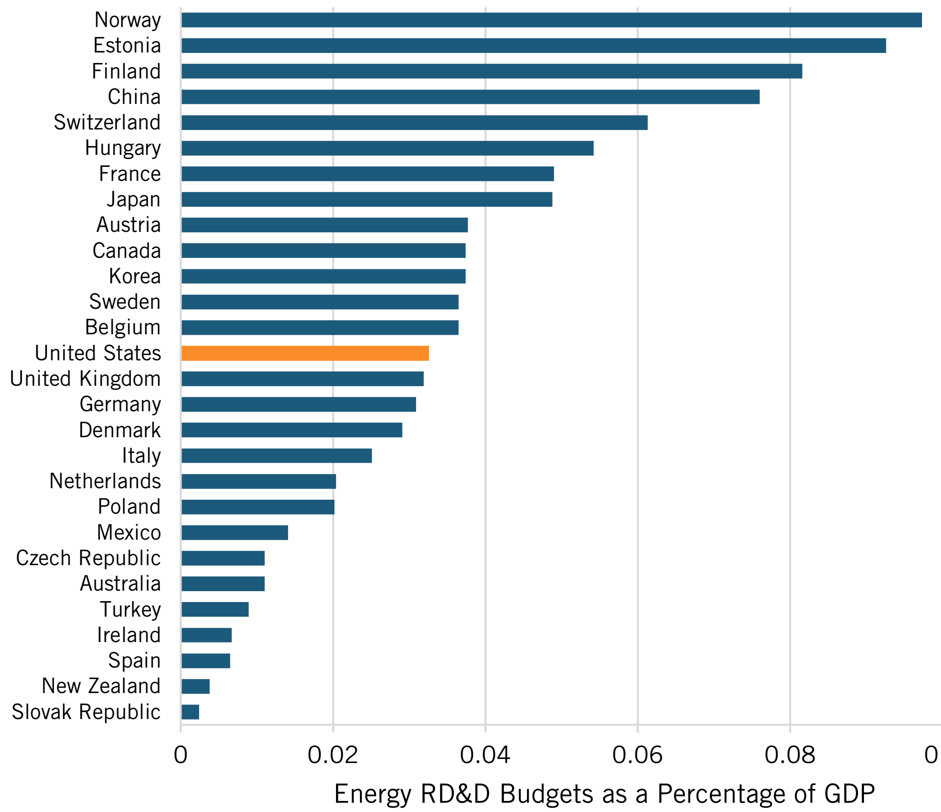
Lack of federal investment is putting U.S. competitiveness in the growing global clean energy industry at risk. While the United States is the world's top funder of energy innovation on an absolute basis, China is rapidly scaling up its energy RD&D investments, and will soon surpass the United States.[41] And 13 other countries invest more in energy RD&D as a share of their economies than the United States (see figure 6).[42] As other countries have stepped up their investments in clean energy, the share of cleantech patents granted to U.S. companies by the U.S. Patent and Trade Office has declined, from roughly 50 percent in 2001 to less than 40 percent in 2016, indicating U.S. leadership in innovation is on the decline.[43]

In 2019, ITIF released a comparative analysis of national energy innovation systems, finding that U.S. leadership in energy innovation is being challenged along multiple fronts, and the U.S. energy innovation system is comparatively weak when it comes to scaling up and commercializing emerging clean technologies. The report evaluates 22 nations and the European Union across 3 essential functions of an innovation system: the ability to generate new clean energy options (option generation); the ability to refine and scale up options into marketable products (scale up); and the extent to which a nation's political, legal, and regulatory institutions provide the social "license to operate" needed for innovations to scale up (social legitimation). The United States ranks third in its ability to generate new clean energy options, owing to its robust support for basic energy-related science research, and its ability to generate new inventions. But the United States comes in 8th in its ability to scale up new energy technologies, and 15th on the social legitimation index. Though the United States has enormous strengths and capacity to innovate, its position as a global leader in clean energy innovation is being challenged by other nations.

For these reasons, many prominent government and industry leaders have recommended doubling or even tripling federal funding for energy RD&D. In 2020, the corporate leaders comprising AEIC reiterated their call for a federal energy RD&D budget of $16 billion annually to bring this sector closer to other advanced technology sectors.[44] In its *Getting to Zero* report, the Center for Climate and Energy Solutions (C2ES) recommended increasing climate-related R&D to $20 billion annually by 2030, and investing $50–100 billion over the next decade for high-impact demonstration projects.[45]

Many congressional leaders have also called for renewed commitment to energy innovation, along with significant increases in federal RD&D. In April 2019, Senator Lamar Alexander (R-TN), who chairs the Energy & Water Appropriations Subcommittee, renewed his call for a "New Manhattan Project for Clean Energy" that would double funding for applied energy RD&D over five years.[46] The subcommittee's ranking member Dianne Feinstein (D-CA) also supports increased investment in energy RD&D. And in January 2020, House Republicans unveiled their plan to address climate change and competitiveness through innovation, which includes doubling funding for basic energy-related science research over five years.[47]

Figure 6: Government energy RD&D investment as a percentage of GDP, 2017[48]



Such an increase is not unprecedented. Congress doubled investment in biomedical research at NIH over a five-year span, from 1998 to 2003. Doing the same for climate- and energy-related research would elevate energy innovation as a national priority and bring funding for clean energy RD&D closer to other national priorities.

THE TRUMP BUDGET: A DRAG ON INNOVATION

The administration's FY 2021 budget fails to meet the moment. Far from putting energy RD&D on a doubling track, it would result in the largest single-year decrease in DOE's history. It is based on three flawed rationales: first, that the private sector will pick up the slack if the federal government withdraws from mid- and late-stage energy technology RD&D; 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; and third, that the government cannot invest in innovation when it is running a budget deficit.

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."[49] The proposed cuts therefore fall most heavily on the applied research, development, and demonstration programs that help technologies scale up (see figure 7).

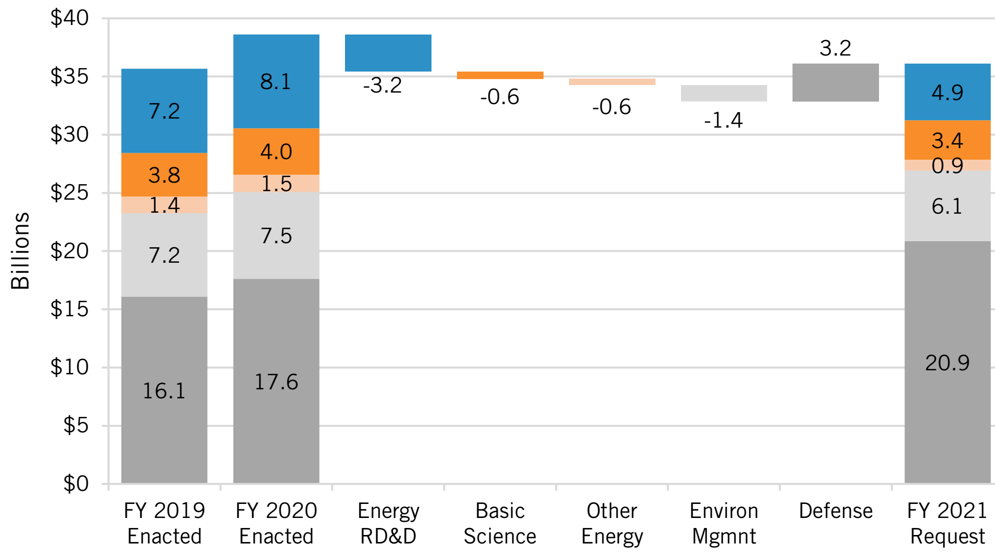
But public support for emerging energy technologies is needed across the innovation spectrum in order to help emerging energy technologies reach full maturity. The administration itself implicitly recognizes the importance of later-stage technology commercialization and tech-transfer programs. In 2018, then-Secretary Rick Perry established DOE's first-ever Chief Commercialization Officer to oversee the department's tech-to-market programs and coordinate tech-transfer activities in order to expand the commercial impact of DOE's RD&D investments.[50] It issued a public request for information to solicit input on ways to "enhance the commercial impact of DOE's portfolio of Research, Development, Demonstration, and Deployment activities."[51] And in early 2020, ARPA-E launched its new Seeding Critical Advances for Leading Energy technologies with Untapped Potential (SCALE-UP) program to help promising technologies that have already passed the proof-of-concept stage receive follow-on support to enable a path to market.[52] OMB's guidance and the administration's budget place DOE in the impossible position of being held responsible for accelerating innovation without being given the tools to do so.

In the last two years, DOE has sought to improve its technology transfer and commercialization activities. But such steps are inconsistent with efforts to slash funding for later-stage applied RD&D.

Energy Secretary Dan Brouillette and other senior DOE officials have also pointed to the relative maturity of the wind and solar industries as justification for budget cuts.[53] Given the complementary roles of the public and private sectors in energy innovation, it makes sense to shift the nature and scale of public support for technologies as they mature. But such shifts should be taken as opportunities to expand investments in less-mature technologies, rather than to cut the budget. Opportunities abound: Offshore wind, concentrating solar power, marine and hydrokinetic power, enhanced geothermal power, algal biofuels, advanced small modular reactors, and many other clean technologies remain far from matching the reliability and low costs of conventional technologies. Yet these are the technologies that are targeted for the most severe cuts.

Moreover, the administration does not consistently apply the principle of shifting support as technologies mature. It continues to prioritize investments in unabated coal combustion technologies, despite coal combustion having provided the majority of U.S. electricity generation for most of the 20th century—and has a much longer history than renewables or nuclear.

Figure 7: Proposed changes in DOE's budget, by major function



A third rationale for cutting the energy innovation budget, which was 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.[54] 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. Senator Alexander noted as such during the FY 2019 appropriations process, when he remarked that "science, research and innovation is what made America first, and I recommend that [President Trump] add science, research and innovation to his 'America First' agenda."[55]

WHAT'S AT RISK

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 8: DOE's RD&D funding by program area, FY 2020

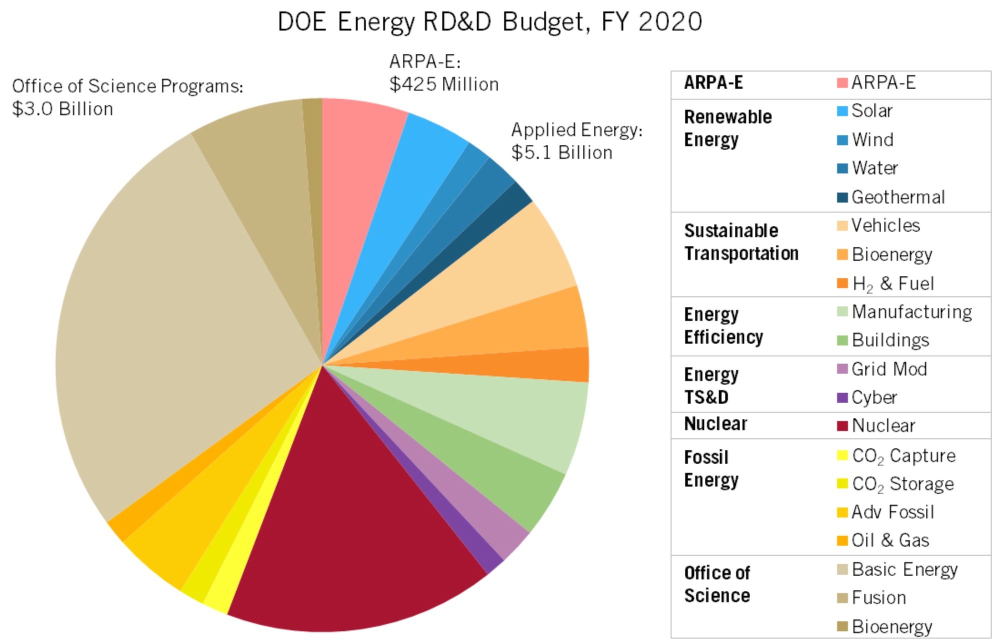


Figure 8 displays the distribution of funds across this portfolio in the current budget (FY 2020), with programs aggregated into groups according to the DOE office that manages them. The bulk of the funding lies in DOE's applied energy offices: Energy Efficiency and Renewable Energy (EERE), which houses the programs in renewable energy, sustainable transportation, and energy efficiency; Electricity (OE); Cybersecurity, Energy Security, and Emergency Response (CESER); FE; and NE. Within 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.

The proposed cuts would hit the most important energy RD&D programs hardest (figure 9). ARPA-E would be completely eliminated, and $311 million in previously appropriated funding would be rescinded. But ARPA-E has proven to be a remarkably versatile catalyst for U.S. energy innovation, funding a wide range of innovative projects outside the technology-specific silos of other program offices. Projects funded by ARPA-E are five times more likely to produce a patent and scientific publication than projects funded by other research programs—one reason why Congress has continued boosting its budget every year since 2013.[56] The Senate Energy and Natural Resources committee and the House Science, Space and Technology committee have both advanced legislation reauthorizing ARPA-E and increasing its budget to $750 million by 2024, nearing the $1 billion level that ITIF and many others have called for.[57]

Within the applied energy programs, the largest cuts are reserved for the Energy Efficiency, Renewable Power, and Sustainable Transportation programs within EERE. Proposed cuts to these programs range from 70 percent for water-power technologies to 83 percent for bioenergy technologies. The State Energy Program, which provides funding and technical assistance for state energy offices, would be eliminated. And the total budget for EERE would be cut by an astounding 74 percent, from $2.8 billion to $720 million.

Nuclear energy also fares badly, notwithstanding recent congressional efforts to jump-start RD&D in advanced nuclear technologies, receiving a 21 percent cut. One bright spot is the inclusion of $295 million to build a versatile test reactor—a user facility that would enable testing of materials and fuel designs in a fast-neutron environment.[58] However, this significant boost comes at the expense of other advanced nuclear innovation priorities. In particular, the Advanced Reactor Demonstrations program, which was just added this year, would be cut from $230 million to $20 million.

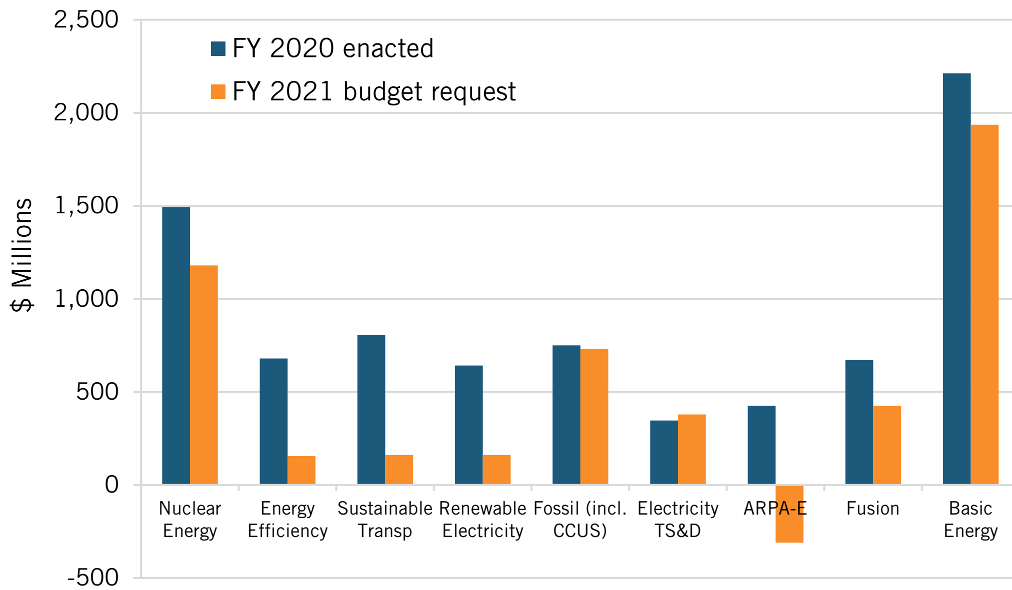
Bright spots in the budget include $40 million for construction of a new Energy Storage Launchpad, and $295 million to build the Versatile Test Reactor.

The Office of Fossil Energy would receive only a 3 percent cut—but that comparatively generous treatment hides damaging priorities. The administration proposes combining the Carbon Capture and Carbon Storage subprograms into a single Carbon Capture, Utilization, and Storage (CCUS) subprogram, while cutting combined funding by 43 percent from $218 million in FY 2020 to $123 million in FY 2021. The Natural Gas Technologies program, which houses the methane emissions quantification and mitigation research activities, would see a 71 percent reduction in funding. Cuts in these emissions-reduction programs are offset by increased funding for the administration's Coal FIRST (Flexible, Innovative, Resilient, Small, Transformative) initiative, which seeks to increase coal exports.

OE and CESER are the only winners among the applied energy programs. OE would get a 3 percent increase, which would cover a 50 percent increase in the Energy Storage subprogram to $84 million, highlighted by a $40 million grid-storage launchpad at the Pacific Northwest National Laboratory.[59] However, the boost in energy storage funding comes at the expense of research in resilient electricity distribution systems, which would get a 60 percent cut. CESER, which includes RD&D in cybersecurity for energy delivery systems—essential for enabling grid modernization—would get a 19 percent boost.

Even basic science research at DOE faces cuts. SC would be slashed by 17 percent, from $7 billion to $5.8 billion. BES and FES—the energy-related programs in SC—would be cut by 13 percent and 37 percent, respectively.

Figure 9: Proposed changes in the DOE energy budget by program office



At the other end of the innovation spectrum, the administration's budget again proposes eliminating the Title 17 loan guarantee program that supports early commercial adoption of complex, capital-intensive technologies such as CCUS, as well as the Advanced Technology Vehicles Manufacturing loan program.[60] Congress's rejection of prior requests for the loan programs' elimination demonstrates its support for this important financial facility.

WHAT HAPPENS NEXT

Congress is unlikely to give this year's budget request any more credence than it has other years' since President Trump was elected. Similar proposals in the prior three budget cycles were soundly rejected by both parties and both chambers. Rather than adopting the administration's proposals, Congress boosted energy RD&D programs by 14 percent in FY 2018, 5 percent in FY 2019, and 11 percent in FY 2020. Senate Budget Committee Chairman Mike Enzi (R-WY) has already said he will not hold a hearing on the president's proposed budget, declaring, "Congress doesn't pay attention to the president's budget exercise."[61]

However, Congress will have to make more difficult choices this year than in the past three. Top-line spending is bound under the agreement reached between Congress and the White House last July that caps non-defense discretionary spending to a 1 percent increase—and congressional leaders have said they do not intend to revisit that agreement.[62]

The next step is for the House and Senate Appropriations committees to apportion the overall discretionary budget to their subcommittees, setting what are referred to as the "302(b) allocations" for each of the 12 bills that fund the government. DOE, along with the Army Corps of Engineers, Department of Interior, and other related agencies, is funded through the Energy and Water Development (E&W) appropriations bill.

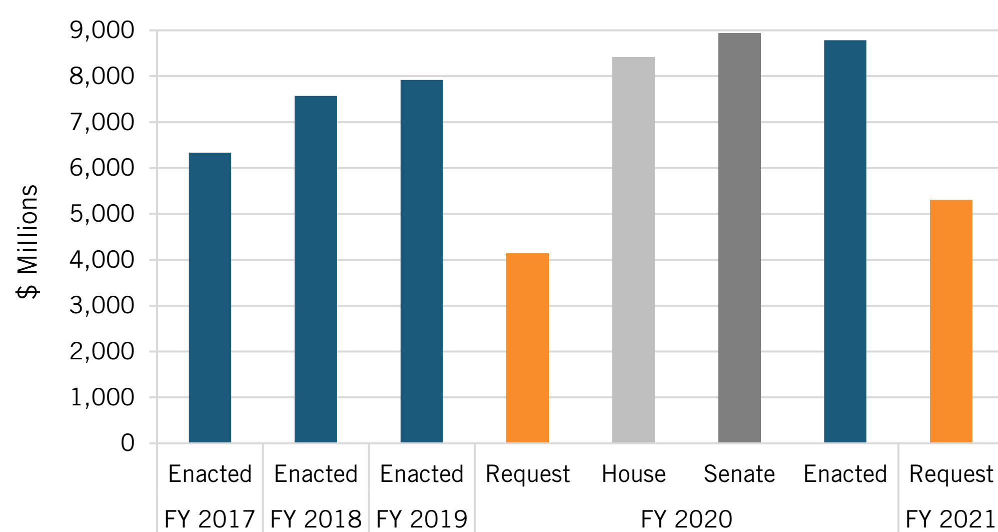
Large increases in federal investments in energy innovation could, in principle, be accommodated within the budget agreement. Because federal energy RD&D accounts for such a small share of the budget (see figure 2), double-digit increases could be offset elsewhere without breaching the cap.

In practice, however, appropriators' ability to increase funding will be limited by each chamber's leadership, which will determine how much money will be allocated to the E&W bill and the 11 others that comprise the budget. Funding levels for most of DOE's programs will likely remain flat or receive only modest increases. Expectations set by the E&W subcommittee chair, Senator Alexander—who called for a "New Manhattan Project for Clean Energy" last April—will undoubtedly not be met.

The House and Senate Appropriations committees have begun holding hearings on the budget, with each chamber producing its own Energy & Water bill as early as May of this year. Ultimately, an appropriations bill is supposed to pass both chambers of Congress and be signed by the president before the next fiscal year begins on October 1, although continuing resolutions that extend current fiscal-year spending levels into the next fiscal year have frequently been used in recent years.

Concurrent with the appropriations process, the House of Representatives may soon take up bipartisan legislation authorizing a diverse array of new RD&D programs and updating the authorizations for many existing programs. The Senate has deferred consideration of such legislation for the moment, but the debate may be reopened before the 116th Congress adjourns.[63] Although these bills may not impact the current appropriations cycle, their passage would open new opportunities to scale up federal energy RD&D spending in pursuit of more ambitious goals.[64]

Figure 10: Energy RD&D programs in the appropriations process, FY 2017–FY 2021[65]



CONCLUSION

Congress has taken the reins of energy innovation policy with a tremendous opportunity to accelerate clean energy and shape the U.S. response to the climate and competitiveness challenges of the 21st century with the decisions it makes in the coming year. It should reject the administration's budget proposal and continue to elevate energy innovation as a national priority.

APPENDIX A

Table 1. President Trump's FY 2020 budget request for DOE, in millions of dollars

	FY 2019 Enacted	FY 2020 Enacted	FY 2021 WH Request	Change
DOE Total Budget	35,685	38,586	35,362	-8%
Defense	16,089	17,611	20,855	30%
Environmental Management	7,175	7,425	6,066	-15%
Basic Science Research	3,755	4,016	3,377	-10%
DOE Energy RD&D Programs*	7,917	8,788	5,311	-40%
ARPA-E	366	425	-311	-173%
Energy Efficiency & Renewable Energy	2,379	2,790	720	-74%
Sustainable Transportation				
Vehicle Technologies	344	396	74	-81%
Bioenergy Technologies	226	260	45	-83%
Hydrogen & Fuel Cell Tech	120	150	42	-72%
Renewable Energy				
Solar Energy	247	280	67	-76%
Wind Energy	92	104	22	-79%
Water Power	105	148	45	-70%
Geothermal Technology	84	110	26	-76%
Energy Efficiency				
Advanced Manufacturing	320	395	95	-76%
Building Technologies	226	285	61	-79%
Fossil Energy R&D	740	750	731	-3%
CCUS and Advanced Power	486	491	546	11%
Natural Gas Technologies	51	51	15	-71%
Unconventional Oil Tech	46	46	17	-63%
NETL Research	51	50	46	-8%
Nuclear Energy	1,326	1,493	1,180	-21%
Reactor Concepts RD&D	324	267	112	-58%
Nuclear Energy Enabling Tech	153	113	116	2%
Fuel Cycle R&D	264	305	187	-39%
Advanced Reactor Demos**	--	230	20	-91%
Versatile Test Reactor***	--	--	295	n/a
Electricity Delivery	156	190	195	3%
Cybersecurity (CESER)	120	156	185	19%
Science	6,585	7,000	5,838	-17%
Basic Energy Sciences	2,166	2,213	1,936	-13%
Fusion Energy Sciences	564	671	425	-37%
BER Bioenergy Research	100	100	100	0%

* Program office totals include some non-RD&D functions. ITIF has estimated total energy RD&D to be approximately $8 billion for FY 2020.
** Advanced Reactor Demonstrations was added as a control point in the FY 2020 appropriations bill.
*** The Versatile Test Reactor was previously funded in FY 2018 and FY 2019 out of the Reactor Concepts RD&D subprogram.

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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ABOUT ITIF

The Information Technology and Innovation Foundation (ITIF) is a nonprofit, nonpartisan research and educational institute focusing on the intersection of technological innovation and public policy. Recognized as the world's leading science and technology think tank, ITIF's mission is to formulate and promote policy solutions that accelerate innovation and boost productivity to spur growth, opportunity, and progress.

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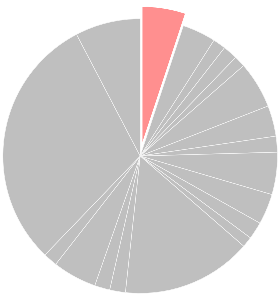
Federal Energy R&D: ARPA-E

BY COLIN CUNLIFF AND BATT ODGEREL | MARCH 2020

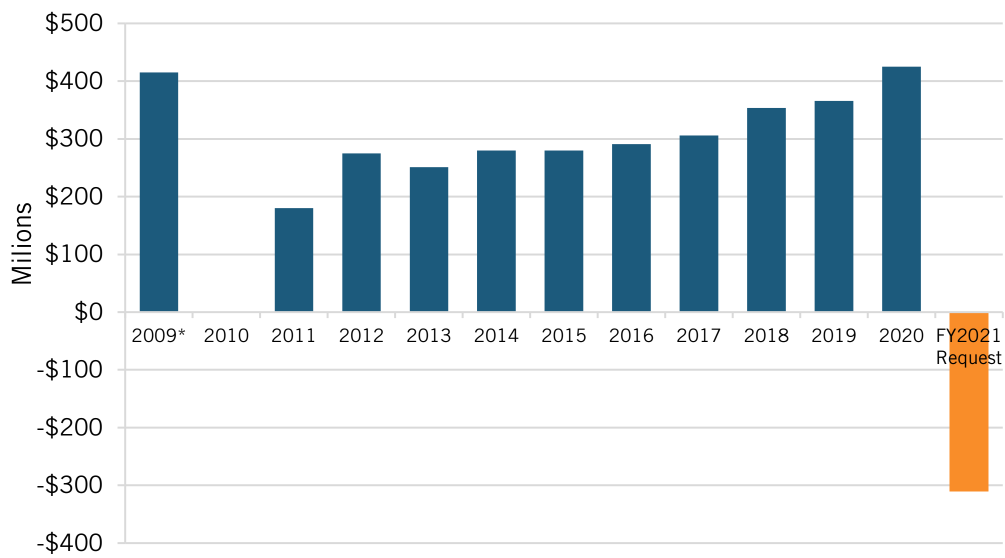
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



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 that are developing technologies to solve critical cross-cutting, real-world problems in transportation, electricity, building, and other sectors.

Figure 1: The FY 2021 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 research and development (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 March 2020, ARPA-E had provided $2.3 billion in R&D funding to over 850 projects; 161 ARPA-E projects had attracted more than $3.2 billion in private-sector follow-on funding;

82 ARPA-E project teams had formed new companies to advance their technologies; and 219 ARPA-E projects had partnered with other government agencies for further development. Moreover, ARPA-E projects have generated 3,658 peer-reviewed journal articles, along with 385 new patents.[3] According to a 2017 ITIF analysis, on average, firms funded by ARPA-E raise more private capital than other clean-energy start-up firms.[4] The Bipartisan Policy Center noted that ARPA-E funded projects that would not have otherwise received funding and that other Department of Energy (DOE) offices have started to adopt ARPA-E's best practices. [5] Congress has continuously shown bipartisan support for the agency.

The American Energy Innovation Act of 2020, introduced with broad bipartisan support, would increase the agency's budget to $750 million by FY 2024.[6] The FY 2021 budget's proposed elimination of ARPA-E would 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 283 projects across 48 active programs, which are broadly organized into four areas: electricity generation; efficiency and emissions; transportation and storage; and grid and grid storage.[7] 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 had raised almost $100 million in equity investment as of late 2018. In June 2019, the California Energy Commission awarded Primus a $4 million grant to increase the company's manufacturing capacity of EnergyPod 2, a long-duration, low-cost zinc bromide flow battery.[8]

- **Rebellion Photonics,** based in Houston, produced monitoring imagers that detect methane leaks in real time to reduce environmental effects from the gas supply chain. The company continued to make progress in its intelligent monitoring platform, the only of a kind that "visually identifies and quantifies gas releases," and demonstrated rapid growths in revenue before it was acquired by Honeywell in December 2019. [9]

- 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 in the Southeast on land not suitable for food production.[10]

Key Elements of the FY 2021 Budget Proposal

ARPA-E would be completely eliminated. Additionally, the budget would rescind $332 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 three years.[11] 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 research, development, and demonstration budget.[12] More recently, NRDC estimated that, as of February 2020, ARPA-E had only allocated 32–52 percent of its FY 2019 funds.[13]

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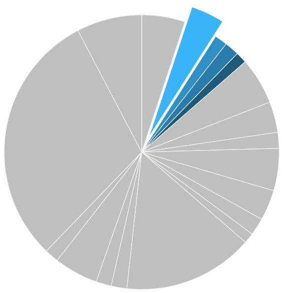


Solar (light blue)
Other Renewables (darker blue)
Energy R&D (light grey)

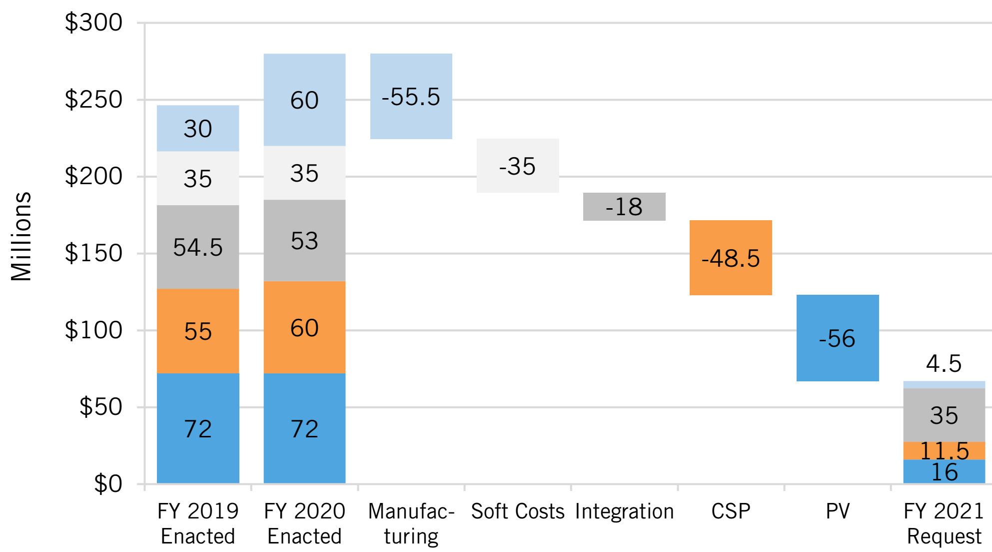
Federal Energy R&D: Solar Energy

BY COLIN CUNLIFF AND BATT ODGEREL | MARCH 2020

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

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 in order to run a steam turbine to generate electricity—and may also be stored for electricity generation at a later time. The program also works to integrate these generation technologies more effectively into the transmission and distribution grid, and to transfer DOE solar innovations to domestic manufacturing capabilities.[1]

Figure 1: The FY 2021 budget request would cut solar energy research and development (R&D) by 76 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 in order 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 40 percent below the 2018 benchmark of $0.05/kWh.[4] Goals for commercial solar ($0.04/kWh) and residential solar ($0.05/kWh) are even more ambitious, requiring cost reductions of more than 60 percent from 2018 benchmark costs.[5] 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.[6]

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.[7] As of 2019, only two CSP developers were operating in the United States. DOE's 2030 goal for baseload CSP systems is $0.05/kWh, or almost 50 percent below the 2018 benchmark of $0.098/kWh.[8] 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:[9]

- **Photovoltaics (PV)** funds R&D 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, multicrystalline and tandem device models, and impacts of outdoor soiling, temperature cycling, ultraviolet light, and humidity.

- **Concentrating Solar Power (CSP)** focuses on component-level R&D in solar collectors, receivers, heat-transfer fluids, power conversion, and thermal-energy storage, as well as integration of subcomponents.

- **Systems Integration** coordinates with the DOE Grid Modernization Initiative to address key grid-integration challenges, including generation variability, voltage control, frequency regulation, system stability, and cybersecurity.

- **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.

- **Manufacturing and Competitiveness** funds the development and demonstration of innovative solar manufacturing technologies in order to increase U.S. competitiveness in solar energy manufacturing.

Key Elements of the FY 2021 Budget Proposal[10]

- **Elimination of the Balance of Systems Soft Costs Reduction subprogram.** Soft costs are the non-hardware costs of installing solar projects, including permitting, inspection, and financing. In the United States, there are 18,000 jurisdictions and 3,000 utilities with different rules and regulations for how to adopt solar, creating barriers for solar adoption and inflating soft costs.[11] For residential systems installed in the United States, soft costs accounted for 63 percent of total system costs in 2018.[12] However, soft costs in Germany (15 percent) and Australia (25 percent) are substantially lower, indicating there is significant potential to lower the cost of solar in the United States.[13] Elimination of this subprogram threatens to derail progress toward the 2020 and 2030 cost goals for residential and commercial solar.

- **A 93 percent reduction in the Manufacturing and Competitiveness subprogram,** including a discontinuation of funding for the SunShot Initiative's Incubator program, which provides early-stage assistance to solar start-ups; and the elimination of all manufacturing and value-chain R&D. The United States' share of global solar PV manufacturing is very small even though tariffs have been imposed on imports on multiple occasions.

- **An 81 percent reduction in the Concentrating Solar Power subprogram**, with no new funding for competitive awards in high-temperature thermal systems and power cycles; and no additional funding for demonstrations of supercritical CO_2 power cycles integrated with thermal storage. The domestic CSP industry appears to be struggling even as foreign markets are beginning to take off, jeopardizing U.S. leadership in the emerging CSP industry.[14]

- **A 78 percent reduction in the Photovoltaic Technologies subprogram**, including a discontinuation of funding for research in thin-film PV materials such as cadmium telluride and perovskites, which might allow the industry to break away from the dominant crystalline-silicon technology, and no new funding for any competitive PV research.

- **A 34 percent cut in the Systems Integration subprogram,** with reduced funding in solar microgrids and hybrid systems that integrate solar with other technologies.

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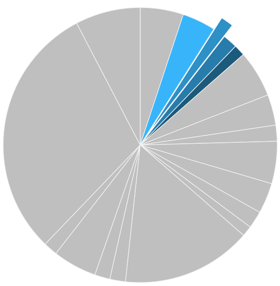
Federal Energy R&D: Wind Energy

BY COLIN CUNLIFF AND BATT ODGEREL | MARCH 2020

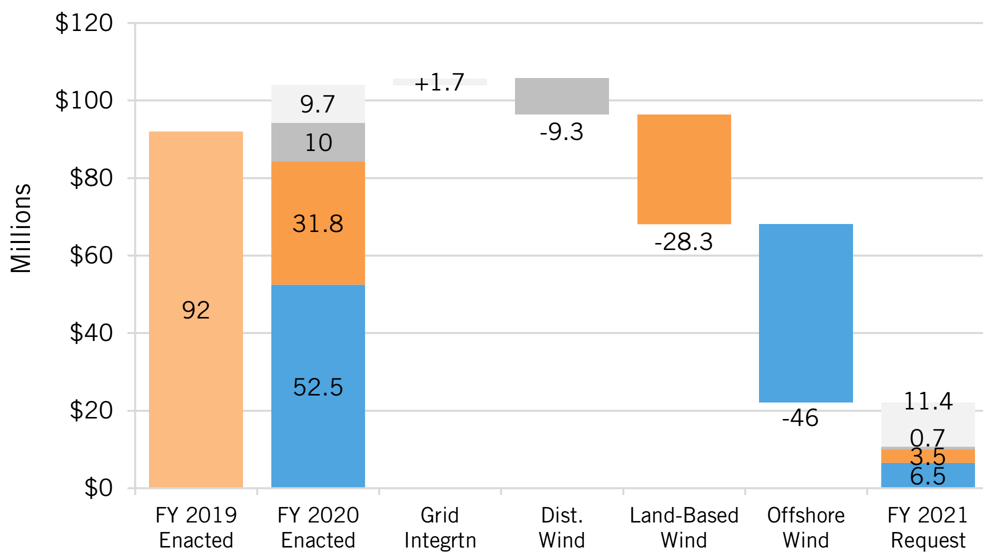
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



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 2021 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 for new wind projects built in 2018 of $0.036/kWh, thus enabling the expansion of wind power to more than 40 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 from the 2017 level 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 also beginning to take off, with 25,824 megawatts (MW) of new offshore wind capacity in the development and operational pipeline as of 2018, of which 2,043 MW have begun permitting processes for construction.[5] In 2019, DOE, along with the New York State Energy R&D Authority (NYSERDA), committed $20.5 million to form a National Offshore Wind R&D Consortium. NYSERDA agreed to match the DOE commitment and has released the solicitation for an award.[6] 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.[7]

Wind Energy R&D Subprograms

R&D in the Wind Energy program is divided into four subprograms:[8]

- **Offshore Wind** focuses on reducing offshore wind technology costs and risks, and improving wind-plant performance, operation, and maintenance given the unique offshore environment in the United States. The subprogram implements the Atmosphere to Electrons initiative, aimed at improving predictions of wind/wave resources in offshore wind development areas; and will continue the existing Wind-Plant Integrated System Design & Engineering Model (WISDEM™) to support offshore wind turbine and plant optimization.

- **Land-Based Wind** R&D focuses on tall wind turbine technology innovations—including those that enable higher hub heights, larger rotors, light-weight components, and improved energy capture—that have the potential to reduce the cost of utility-scale land-based wind, and also seeks technical solutions to environmental and siting challenges to land-based wind energy. The subprogram also supports Sandia's Scaled Wind Farm Technology (SWiFT) which uses multiple wind turbines to measure turbine performance in a wind farm environment. [9]

- **Distributed Wind** focuses on the integration of distributed wind energy with other distributed energy resources in hybrid plants and microgrids. To that end, the subprogram supports research in a range of areas, including balance of system cost reduction and atmospheric physics for site assessment.

- **Systems Integration,** which would include the former Grid Integration & Analysis program, promotes R&D in ensuring a cost-effective, reliable, and resilient power system with growing levels of supply from land-based, offshore, and distributed wind energy resources.

Prior to FY 2020, DOE structured its Wind Energy subprograms differently, so FY 2019 subprograms (light orange in figure 1) are not directly comparable. DOE made the change to the current structure to better comply with congressional direction.

Key Elements of the FY 2021 Budget Proposal[10]

- **An 88 percent reduction in Offshore Wind,** including no funding for competitively awarded projects to improve offshore wind resource characterization and forecasting; no funding for offshore development and demonstration projects; reduced funding for National Laboratory-led turbine and foundation projects; no funding for research to evaluate the environmental performance of offshore wind plants. The offshore wind industry is already taking off in Europe, leaving the United States at risk of falling behind without further investment.

- **An 89 percent reduction in Land-Based Wind,** with reduced funding for the research test facilities at National Renewable Energy Laboratory's (NREL)'s Flatirons Campus and Sandia's SWiFT facility, which would be kept in standby mode; reduced funding for adaptive load control technologies within the Big Adaptive Rotor initiative; no funding for competitive award for Tall Tower Demonstration, a program designed to address constraints to tall wind turbine towers; and continued support for the American Wake Experiment (AWAKEN), a planned international wake observation and validation campaign for wind-farm modeling.

- **A 93 percent reduction in Distributed Wind,** with reduced funding for testing and reliability; and reduced funding for wind technologies associated with military design requirements. Existing efforts regarding integration of distributed wind with storage and other distributed energy resources transitioning to the Systems Integration subprogram.

- **An 18 percent increase in Systems Integration, Analysis, and Workforce subprograms,** including continued funding for gird modernization activities; the distributed wind Microgrid, Infrastructure Resilience and Controls Launchpad (MIRACL), which supports integrating distributed wind in hybrid wind/solar/storage systems and microgrid applications; and new funding for advanced planning and operation models and tools for offshore wind integration.

ENDNOTES

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Federal Energy R&D: Water Power

BY COLIN CUNLIFF AND BATT ODGEREL | MARCH 2020

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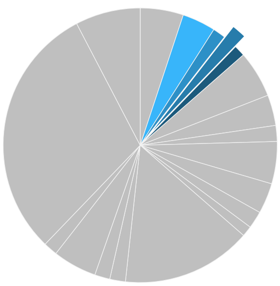
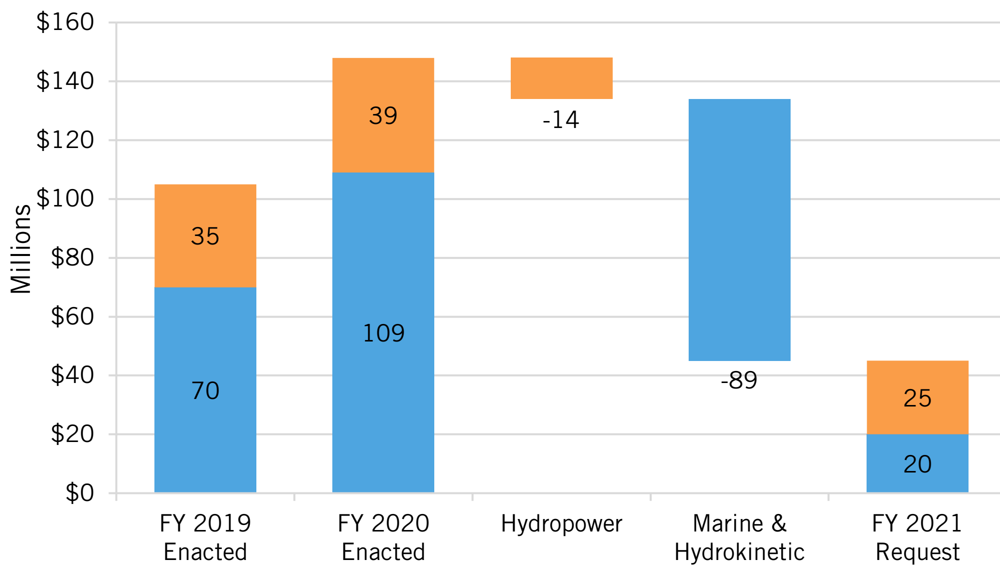


Water (blue)
Other Renewables (blue)
Energy R&D (light grey)

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.[1]

Figure 1: The FY 2021 budget request would cut water power R&D by 70 percent.[2]



What's at Risk

Hydropower is the second-largest source of renewable energy, providing nearly 7 percent of the nation's electricity (and 18 percent of its carbon-free electricity) for the first 11 months of 2019.[3] And pumped-storage hydropower accounts for more than 90 percent of U.S. grid-scale electricity storage, far more than lithium-ion batteries.[4] However, installed capacity of conventional hydropower and pumped-storage hydropower has stalled at about 100 gigawatts (GW), and innovation is needed to jump-start 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.[5] DOE recently launched the Hydropower and Water

Innovation for a Resilient Electricity System (HydroWIRES) to improve conventional hydropower and pumped-storage hydropower's contributions to the grid, and to roadmap future research directions.[6]

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.[7] 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 they 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 in order to tap into new markets and provide new energy services.[8] 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:[9]

- **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 begin operation between 2021 and 2022—that will allow testing and validation of industry-developed MHK energy-conversion components and systems.[10] 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.[11]

Key Elements of the FY 2021 Budget Proposal[12]

- **An 82 percent reduction in the MHK Technologies subprogram**, including no new funding for infrastructure upgrades at the three National Marine Renewable Energy Centers in Oregon, Hawaii, and Florida; no funding for technical assistance in MHK technologies to remote communities; no funding for the development of advanced materials or durability testing; no funding for university partnerships to support foundational R&D in marine energy systems development; and reduced funding for development and testing of MHK systems and components, as well as wave-powered desalination systems.
- **A 36 percent reduction in the Hydropower Technologies subprogram**, including reduced R&D funding for advanced manufacturing techniques for modular hydropower technologies; no new funding to develop a low-impact hydropower test facility; the elimination of incentives for deployment of hydropower at existing non-powered dams; and increased funding for grid integration R&D through the HydroWIRES Initiative.

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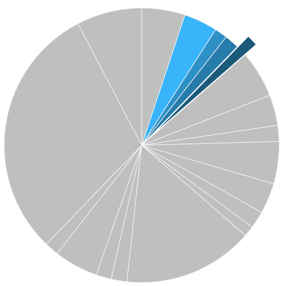
Federal Energy R&D: Geothermal Technologies

BY COLIN CUNLIFF AND BATT ODGEREL | MARCH 2020

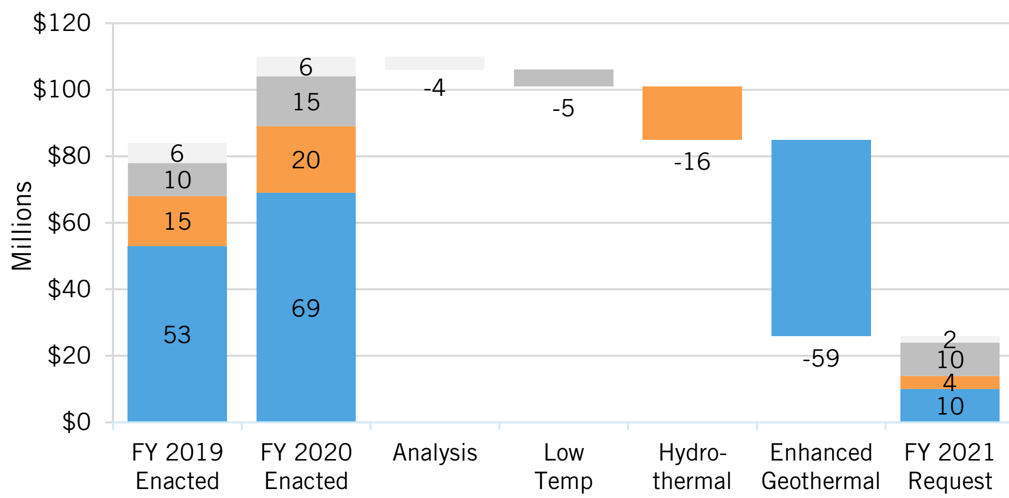
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



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 with steam turbines. The Geothermal Technologies program supports research and development (R&D) 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. 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 2021 budget request would cut geothermal R&D by 76 percent[2]



What's at Risk

In addition to the current U.S. installed capacity of geothermal energy of over 3.8 gigawatts (GW), there is a vast source of untapped energy just waiting to be realized. DOE's 2019 report *GeoVision: Harnessing the Heat Beneath Our Feet,* found that technological improvements and cost reductions could increase geothermal capacity to 60 GW by 2050.[3] The geothermal industry operates in a harsh subsurface environment in which unique technical and operational challenges must be overcome in order 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 costs and risk of development. The Department of Energy (DOE) set a goal of reducing the cost of electricity from enhanced geothermal systems (EGS) to $0.06/kWh by 2050, which would make them competitive with other dispatchable baseload power.[4]

In addition, the United States has abundant low-temperature geothermal resources below 300 degrees F (150°C), with potential applications for residential and commercial heating and cooling, district heating and cooling, industrial process heating, and underground thermal energy storage. The *GeoVision* analysis found that the market potential for geothermal heat pumps is equivalent to supplying heating and cooling to 28 million households, which is 14 times more than the current installed capacity. Furthermore, district-heating geothermal systems could meet the heating and cooling demands of 45 million households in 2050.[5]

But realizing the enormous potential of America's domestic low-carbon geothermal resources requires R&D to harness them more effectively, develop improved methods to stimulate new resources, and characterize and model subsurface stress and other reservoir properties. 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 into four subprograms:[6]

- **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 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.[7]
- **Hydrothermal R&D** focuses on technologies necessary to find and access "blind" conventional hydrothermal resources—or geothermal resources that require little-to-no stimulation to improve permeability and fluid flow, and are without clear surface expressions—by targeting innovative approaches to microhole drilling applications, self-healing cements, and subsurface imaging.
- **Low-Temperature and Coproduced Resources** targets research, development, and demonstration (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.
- **Data, Modeling, and 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. [8]

Key Elements of the FY 2021 Budget Proposal

- **No new funding for the Frontier Observatory for Research in Geothermal Energy (FORGE),** DOE's flagship geothermal research facility in Milford, Utah, aimed at developing and piloting EGS technologies. The FY 2021 budget proposal would operate FORGE through FY 2024 solely on previously-appropriated funding.
- **An 86 percent decrease in the EGS subprogram**, including the elimination of funding to design a seismic monitoring system; no new funding for FORGE pilot wells or near-field demonstration wells; and no funding for GEOTHERMICA, an international collaborative effort to advance EGS knowledge.
- **An 80 percent reduction in the Hydrothermal subprogram**, including no new funding for subsurface R&D to develop technologies to characterize and monitor subsurface stress; no new funding to apply machine learning to geophysical data; and no new funding for exploration RD&D to discover geothermal resources with no surface expression.
- **A 33 percent reduction in the Low Temperature subprogram,** including no new funding for geothermal district heating analysis; and no new funding to proceed with demonstration of a geothermal district heating system on a university campus.
- **A 67 percent decrease in the Data, Modeling, and Analysis subprogram**, including no new funding to continue the *GeoVision* nontechnical barriers study, which would build on the 2019 *GeoVision* report to evaluate opportunities to reduce geothermal soft costs.

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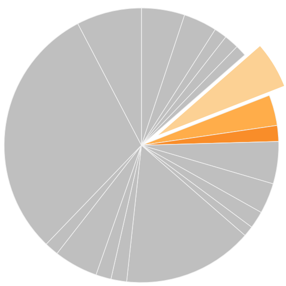
Federal Energy R&D: Vehicle Technologies

BY COLIN CUNLIFF AND BATT ODGEREL | MARCH 2020

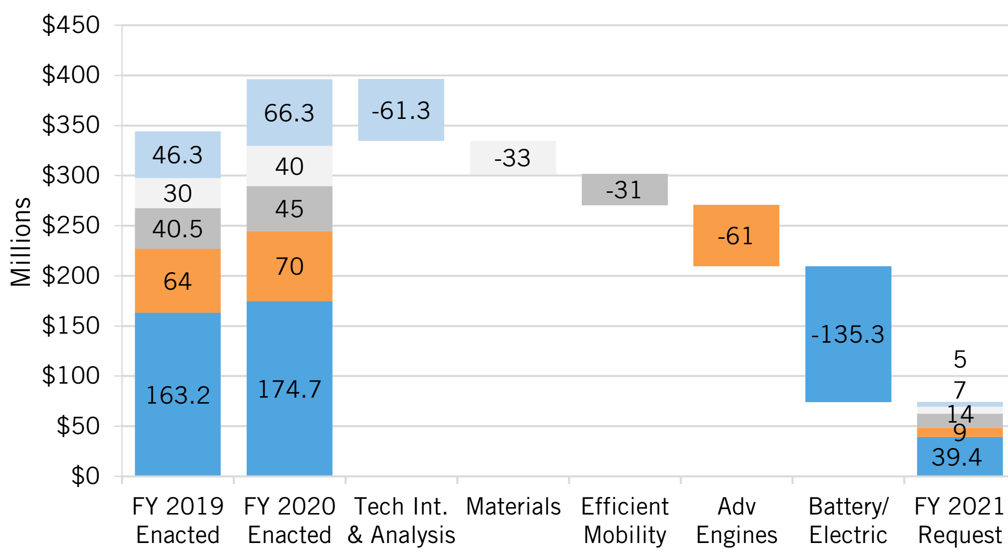
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



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

The transportation sector accounted for 69 percent of petroleum use and 33 percent of all carbon pollution in 2018, 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 11.4 percent of U.S. petroleum consumption coming from net imports, U.S. consumers on average send more than $4.5 billion per month overseas for crude oil.[3] By investing in research and development (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 2021 budget request would cut vehicle technologies R&D by 81 percent[5]



What's at Risk

VTO 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 batteries to 100 dollars per kilowatt-hour ($100/kWh), increasing their range to 300 miles, and decreasing charging time to 15 minutes or less by 2028, with an ultimate cost goal of $60/kWh. But new battery chemistries will be needed to reach these cost targets and for EVs to achieve their full potential. China is currently leading the world in EV deployment, while the European Union is moving quickly to catch up and secure its own EV supply chain.[6] Reductions in battery and electrification R&D funding threaten to delay progress that would help move the United States toward a similar track.

The SuperTruck II research activity set a target of doubling the freight-hauling efficiency of heavy-duty Class 8 long-haul trucks by 2020, over the 2009 efficiency level.[7] Long-haul trucking is a key “hard-to-decarbonize” transportation subsector that is not amenable to electrification using the same lithium-ion batteries used in light-duty EVs. Improving efficiency is one of the few good near-term options for lowering energy costs and reducing carbon emissions from this sector.[8] The Department of Energy (DOE) has also established goals to improve mobility efficiency through connected, shared, and autonomous vehicles, and to identify novel high-strength structures that can reduce vehicle weight and improve fuel economy. Reduced funding for these programs threatens 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** 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 both to develop advanced combustion engines and to 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.

- **Data, Modeling, and Analysis** provides technology, economic, and interdisciplinary analyses to inform and prioritize the Vehicle Technologies research portfolio.

Key Elements of the FY 2021 Budget Proposal

- **A 77-percent reduction of the Battery and Electrification Technologies subprogram,** including an $85 million cut for battery R&D; no new funding for battery development work through the Advanced Battery Consortium; a $35.6 million cut to electric-drive R&D; no funding to develop advanced motor and inverter drive systems that do not rely on heavy rare earth minerals; a $14.7 million cut to electrification R&D; and no funding for smart charging systems, high-power charging systems, or wireless charging systems.

- **No new funding for SuperTruck II activities,** a cross-cutting activity that aims to double the freight-hauling efficiency of heavy-duty Class 8 long-haul trucks by 2020.[10] DOE is launching new research activities to build on the success of SuperTruck II, but is providing significantly reduced funding.

- **An 87-percent reduction of Advanced Engine & Fuel Technologies R&D,** including no funding for lightweight high-efficiency engine research projects; no funding to improve efficiency and reduce harmful emissions from off-road vehicles, including agricultural vehicles; the elimination of research on spark-ignited engines; and reduced funding for emission reduction of diesel engines.

- **A 69-percent reduction in Energy Efficient Mobility Systems,** including reduced funding for the Systems and Modeling for Accelerated Research in Transportation (SMART) National Laboratory Consortium; and a $13 million cut to research in connectivity and automation technologies.

- **An 83-percent reduction in Materials Technology R&D,** including the elimination of research on lightweight metal alloys and on-vehicle applications, projects utilizing the LightMAT Consortium to accelerate the discovery of advanced materials, and research on lightweight high-efficiency engines.

- **An 89-percent reduction in Technology Integration,** including no new funding for the Clean Cities program, and minimal support for the advanced vehicle technology competition for university students.

- **A 75-percent reduction in Data, Modeling, and Analysis,** including reduced funding for techno-economic analyses to inform research portfolio planning.

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Federal Energy R&D: Bioenergy Technologies

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BY COLIN CUNLIFF AND BATT ODGEREL | MARCH 2020

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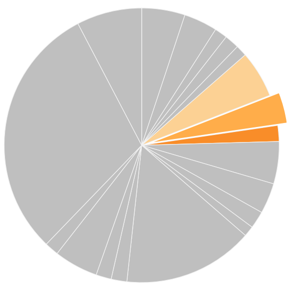
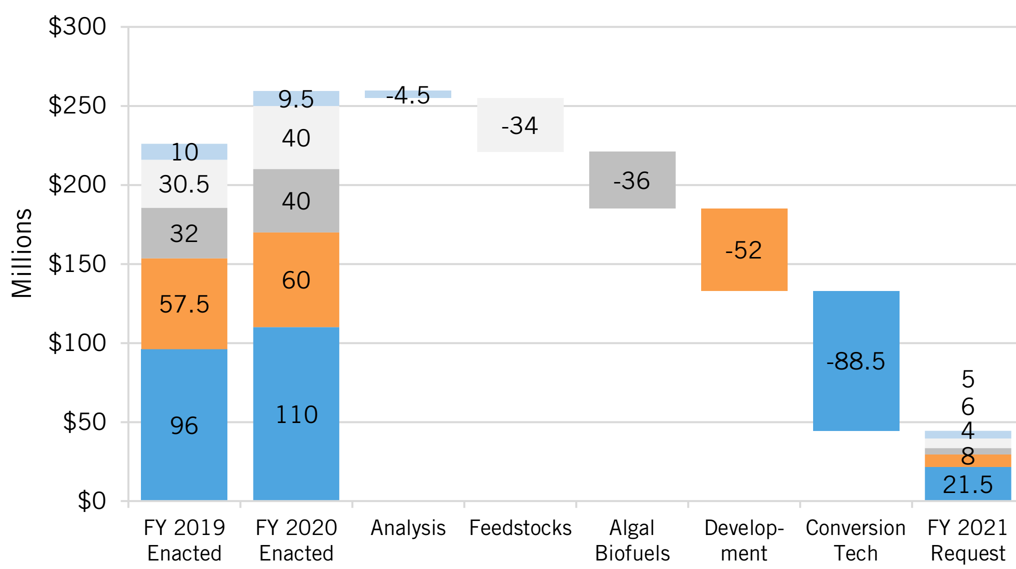


Bioenergy (orange)
Other Transportation (orange)
Energy R&D (light grey)

The Department of Energy's (DOE) Bioenergy Technologies Program (BETO) focuses on research and development (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 such as switchgrass and algae. The program's primary R&D focus is on creating "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. Transportation is the largest greenhouse gas-emitting sector in the United States, having surpassed electric power in 2016.[1]

Figure 1: The FY 2021 budget request would cut bioenergy technologies R&D by 83 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 kilowatt-hours (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 (BGY)—about 20 percent of the current domestic jet-fuel market—by 2030, and 20 BGY in the long run.[5] And a number of bioenergy pathways, combined with carbon sequestration technologies, offer the potential to remove carbon dioxide from the atmosphere, resulting in carbon-neutral or even carbon-negative bioproducts.[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 would 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 Technologies** 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 Feedstock Conversion Interface Consortium (FCIC), a consortium of eight national laboratories focused on feedstock handling, preprocessing, and conversion opportunities to reduce the sales price of biofuel.
- **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** focuses on converting biomass feedstocks into "drop-in" hydrocarbon transportation fuels and coproduced bioproducts, and explores both biological and thermochemical conversion pathways.
- **System Development and Integration** works to scale up integrated biorefinery systems, and focuses on both the development, testing, and verification of biorefinery processes, and the identification of new market opportunities for bioproducts.
- **Data, Modeling, and Analysis** provides quantitative analysis to inform BETO decisions regarding the future direction and scope of its R&D portfolio.

Key Elements of the FY 2021 Budget Proposal

- **No new funding for integration of CO_2 Direct Air Capture (DAC) with algal biofuel production.** Direct air capture (DAC) technologies remove carbon dioxide directly from the atmosphere, offering the potential for carbon-neutral or even carbon-negative applications. Algal bioenergy systems often use carbon dioxide as a feedstock. In FY 2020, DOE issued a new competitive funding opportunity to integrate DAC technologies with algal bioproduct systems, with the goal of reducing both algae biomass production costs and net carbon emissions.[8]

- **An 87 percent reduction in System Development and Integration,** including the elimination of research on bio-based fuels for spark-ignition; no additional funding for integrated process development and pilot-scale systems research; no funding for demonstration scale projects; and no funding for sustainable aviation fuels or marine biofuels.

- **A 90 percent reduction in Advanced Algal Systems,** including no funding for research on integration of algae with wastewater treatment; and reduced funding in microalgal resource assessment modeling, and algal and terrestrial feedstock blending.

- **An 80 percent reduction in Conversion Technologies R&D,** including no funding for research on biological upgrading of sugars and aqueous waste streams, and improving biological process operations; no funding for competitively selected projects on community-scale digesters; no funding for aerobic upgrading; no funding for the Feedstock Conversion Interface Consortium or the joint bioenergy research initiative with the U.S. Department of Agriculture; reduced funding for the Agile BioFoundry; and reduced funding for waste feedstock utilization.

- **An 85 percent reduction in Feedstock Technologies,** including no funding for competitive research to reduce the costs of feedstock logistics; reduced funding for FCIC; and reduced funding for R&D on harvest logistics and quality assurance, biomass densification, and biomass analytics.

- **A 47 percent reduction in Data, Modeling, and Analysis**, including no funding for analysis of integrated landscape management strategies to reduce biofuel costs; and no funding for testing energy crops that improve soil quality and water retention.

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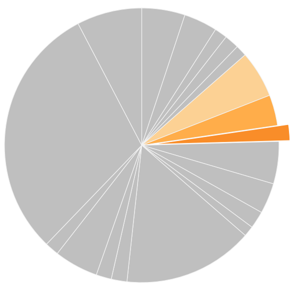
Federal Energy R&D: Hydrogen & Fuel Cells

BY COLIN CUNLIFF AND BATT ODGEREL | MARCH 2020

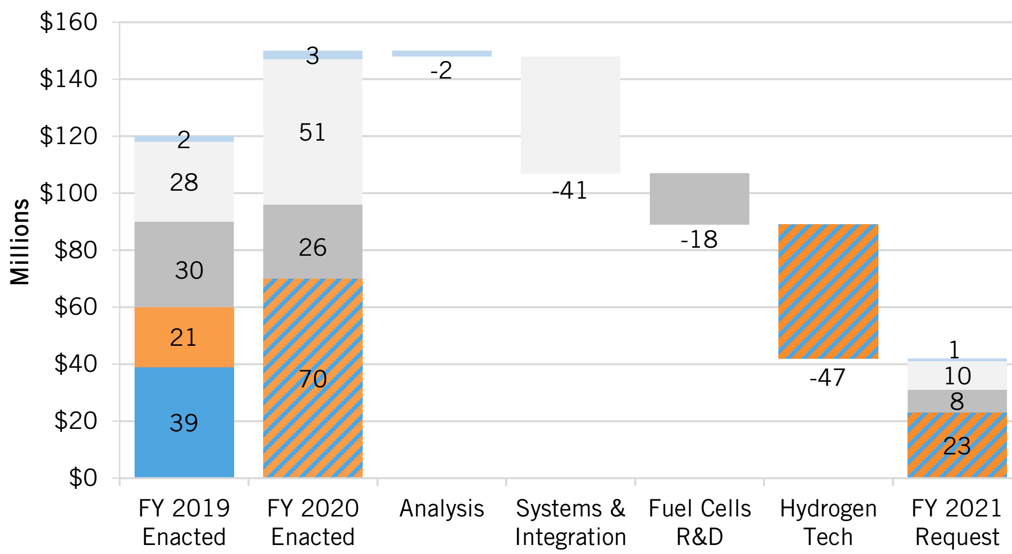
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



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

Fuel cells use the chemical energy of hydrogen and similar fuels 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 research and development (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 2021 budget request would cut hydrogen and fuel-cell R&D by 72 percent[2]



Note: The Department of Energy (DOE) is proposing to merge the Hydrogen Fuel (blue) and Hydrogen Infrastructure (orange) subprograms into a single Hydrogen Technologies subprogram in its FY 2021 request (diagonal orange/blue stripes in figure 1).

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 for light-duty cars include decreasing fuel cell costs to 30 dollars per kilowatt ($30/kW), decreasing onboard hydrogen storage costs to 8 dollars per kilowatt-hour ($8/kWh), 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 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 kilogram ($2/kg) and approximately $1/kg for energy storage and chemical processes, with a system-wide cost (hydrogen production plus delivery and storage) of $4/kg 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 a source of high-temperature heat for industrial applications.[6] Because of the wide range of its 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 production and delivery systems and end-use applications.

Hydrogen & Fuel Cells R&D Subprograms

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

- **Fuel Cell Technologies** 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 and heavy-duty trucks.
- **Hydrogen Fuel R&D** focuses on novel hydrogen production—including hydrogen production by electrically splitting water—and storage technologies, as well as direct conversion of natural gas to hydrogen and carbon coproducts (beyond the conventional steam methane reforming process). The FY 2021 budget request proposes merging the subprogram with Hydrogen Infrastructure R&D.
- **Hydrogen Infrastructure R&D** focuses on reducing costs of such hydrogen fueling infrastructure systems as liquid pumps, compressors, storage, chillers, dispensers, and other hydrogen delivery and station components.
- **Data, Modeling, & Analysis** performs analytical research that provides a technical basis for informed decision-making for the program's R&D direction and prioritization.
- **Systems Development & Integration** focuses on developing the technologies to integrate hydrogen systems with a wide range of sectors, including marine, trucking, rail, steelmaking, ammonia production, electrofuels production from CO_2 and renewable and nuclear resources.

Key Elements of the FY 2021 Budget Proposal

- **A 69 percent reduction in Fuel Cell Technologies**, including reduced funding for the Fuel Cell Performance and Durability (FC-PAD) consortium; reduced funding for high-temperature proton exchange membrane R&D that aids efficient fuel cell operation; no new funding for alkaline-membrane fuel cell technologies; and no funding for reversible fuel cells that can store energy and generate power.

- **A 67 percent reduction in the Hydrogen Technologies,** 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 hydrogen production from water splitting; and reduced funding for the Hydrogen Materials Advanced Research Consortium (HyMARC), an R&D effort to reduce the cost of hydrogen storage.

- **An 80 percent reduction in Systems Development & Integration,** with no funding for industry-led projects to reduce the cost of polymer electrolyte membrane electrolyzer manufacturing technologies; reduced funding for hydrogen use in steel manufacturing; reduced funding for R&D to enable adoption of codes and standards applicable to hydrogen and fuel-cell technologies for large-scale applications; and new funding for research focused on improving the energy and operational efficiency medium-duty and heavy-duty trucks.

- **A 67 percent reduction in Data, Modeling & Analysis**, including a narrowed focus on emerging applications of hydrogen and fuel cell technologies; and no funding for analysis of the potential for hydrogen generation through nuclear baseload sources.

ENDNOTES

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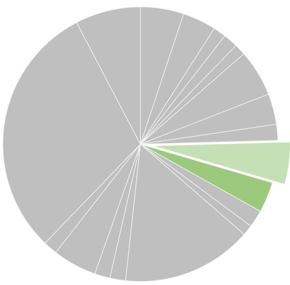
Federal Energy R&D: Advanced Manufacturing

BY COLIN CUNLIFF AND BATT ODGEREL | MARCH 2020

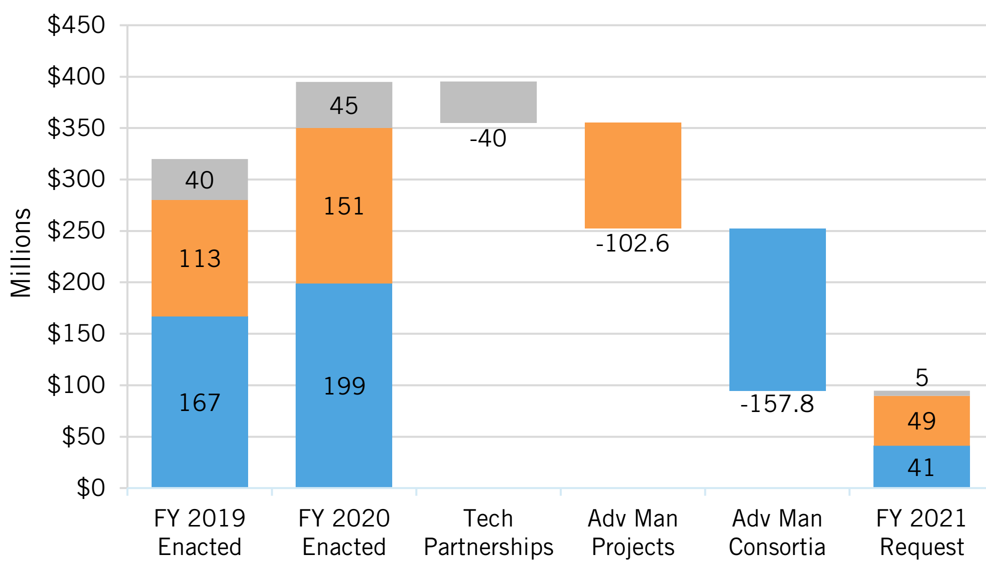


Manufacturing (light green)
Other Efficiency (green)
Energy R&D (light gray)

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

The Department of Energy's (DOE) Advanced Manufacturing Office (AMO) works to improve the energy efficiency and productivity of U.S. manufacturers by focusing research and development (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 2021 budget request would cut advanced manufacturing R&D by 76 percent[2]



What's at Risk

Employing over 12 million people across the nation, 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 manufactured products used by the energy industry would strengthen U.S. manufacturing and hasten progress toward national economic, workforce, security, and climate goals. Market failures, however, lead to many gaps in the private-sector response to the manufacturing and climate 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]

The Clean Energy Manufacturing Innovation (CEMI) Institutes are central to AMO's efforts to accelerate innovation in key technology areas: wide band-gap semiconductor manufacturing; carbon-fiber composite manufacturing; smart manufacturing; chemical process intensification; and sustainable manufacturing—with plans for a sixth institute in cybersecurity underway. The institutes were originally funded at $14 million per year for 5 years, with a requirement of at least a 50/50 cost-share from private-sector partners. DOE has adopted a five-year window for CEMI institutes to transition to other funding sources; however, comparable programs in other countries receive core institutional funding from the government on a permanent basis. ITIF has previously recommended that DOE provide ongoing funding, contingent on continued industry participation, beyond the initial five-year window.[4]

AMO has primarily focused on reducing the energy intensity of manufacturing. The Information Technology and Information Foundation (ITIF) and other research organizations have recommended expanding the mandate of AMO to include decarbonization of the industrial sector, which comprises about a quarter of global emissions, including many of the most difficult-to-decarbonize sources.[5] In the FY 2020 budget cycle, the Senate directed AMO to develop a series of sector-specific decarbonization roadmaps to guide R&D activities across DOE.[6] While encouraging, such a refocusing should be accompanied by a significant scale-up in funding—the industrial sector accounts for 22 percent of direct U.S. greenhouse gas emissions, but AMO accounts for only 6 percent of DOE's total applied energy research investments.[7]

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.[8]

- **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.

- **R&D Consortia** bring together manufacturers, research institutions, suppliers, and universities in public-private R&D partnerships, 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 CEMI institutes that focus on clean energy technologies; the Energy-Water Desalination Hub; and the Critical Materials Hub.[9]

- **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 and waste heat to power technologies to improve efficiencies and lower energy costs.

Key Elements of the FY 2021 Budget Proposal

- **Elimination of the CEMIs**, which could stall progress in key manufacturing challenges and put domestic manufacturers at a disadvantage to international competitors.

- **A 79 percent reduction in R&D Consortia**, including termination of the CEMIs, the Energy-Water Desalination Hub, and the Critical Materials Institute; reduced funding for the Oak Ridge MDF and CFTF; no funding for additive manufacturing nanocellulosic feedstock materials; and reduced funding for consortia led by universities and National Laboratories.

- **A 68 percent reduction in R&D Projects**, with a $91 million cut to manufacturing process R&D, including no funding for enhanced drying, wastewater, and chemical processes; reduced funding for the High-Performance Computing for Manufacturing (HPC4MFG) projects; and a $9 million cut to advanced energy storage research, including reduced funding for R&D on lithium ion-based battery manufacturing.

- **Elimination of 31 Industrial Assessment Centers and the Combined Heat-and-Power Technical Assistance Partnerships,** which provide technical assistance to small and medium-sized manufacturers to improve their energy productivity and reduce energy costs. Overall funding for the Technical Partnerships program would decline by 89 percent.

ENDNOTES

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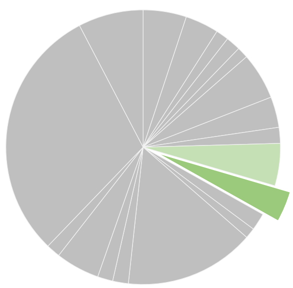
Federal Energy R&D: Building Technologies

BY COLIN CUNLIFF AND BATT ODGEREL | MARCH 2020

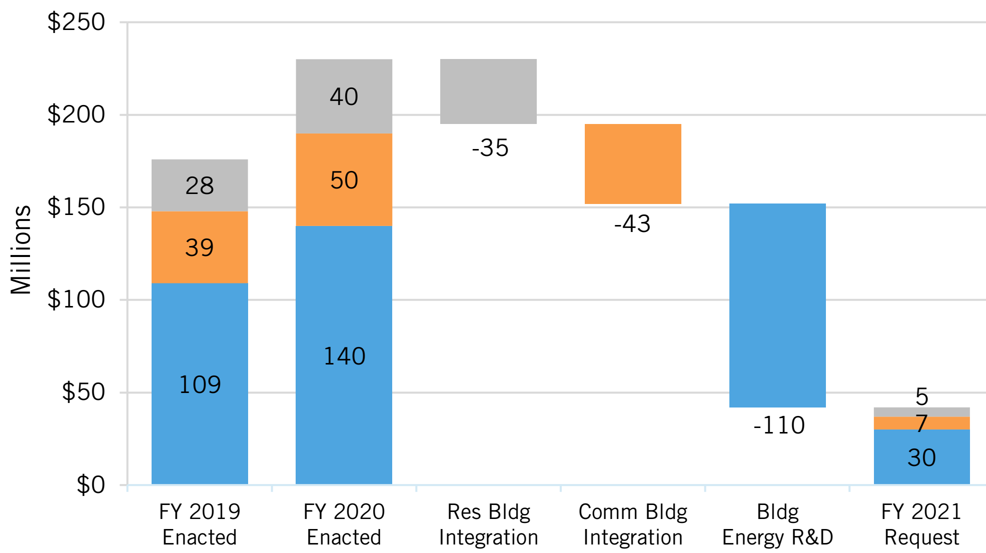
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



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) to advance 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, as well as the building envelopes themselves. BTO also works on improved energy modeling and system controls to predict and manage energy-efficient appliances/equipment, and system and whole-building energy usage.[1]

Figure 1: The FY 2021 budget request would cut building technologies R&D by 79 percent[2]



What's at Risk

Residential and commercial buildings are the single largest energy-consuming sector in the U.S. economy, accounting for 71 percent of the nation's electricity use and 39 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 from the 2010 levels the average energy use per square foot of all U.S. buildings by 30 percent by 2030, with a long-term goal of reducing energy intensity of homes and commercial buildings by 50 percent or more.[5] In addition to these whole-building targets, 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 in energy costs annually.[7]

BTO also supports collaborative partnerships through the Better Buildings Initiative (BBI) to accelerate the rapid uptake and continued improvement of building innovations, and to develop new resources to lower energy costs. Through BBI, the Department of Energy (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 32 of the country's Fortune 100 companies, 12 of the top-25 U.S. employers, 12 percent of the U.S. manufacturing energy footprint, and 13 percent of total commercial building space, as well as 17 federal agencies, 28 states, 90 local governments, and 8 national labs. As a result of innovative energy solutions developed through BBI, its partners have reported an estimated cost savings of $8.4 billion, 1.38 quadrillion Btus in energy savings, and 82 million tons of avoided CO_2 emissions since 2011, while partnerships with other federal agencies have resulted in over $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; lighting; heating, ventilation and air-conditioning & refrigeration; windows & envelope; solid-state lighting; and building energy modeling.

- **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, and 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 stakeholder networks such as BBI 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 demonstrate and validate innovative technology solutions through its Advanced Building Construction (ABC) initiative—an effort that integrates energy efficiency solutions into construction practices—Building America, Zero Energy Ready Homes, and BBI.

Additionally, the Equipment and Building Standards subprogram implements statutory requirements to set minimum efficiency standards for appliances and equipment.

Key Elements of the FY 2021 Budget Proposal

- **An 86-percent reduction in the Commercial Buildings Integration subprogram,** including no funding for BBI, which has helped over 900 organizations save $8.5 billion in energy costs; the elimination of all later-stage development and commercialization activities, such as the High Impact Technology Innovation Catalyst; and reduced funding for energy systems integration (e.g., integrated HVAC and lighting) research.[10]

- **An 88-percent reduction in the Residential Buildings Integration subprogram,** including elimination of funding for all later-stage development and commercialization activities, including Home Performance with ENERGY STAR, Better Buildings Residential, and public-private demonstration projects; no new funding for the ABC initiative; the elimination of all technical assistance activities, including to state and local governments, utilities, residential contractors, builders, building owners and operators, and other key residential sector stakeholders; and reduced funding for systems integration research.

- **A 79-percent reduction in Building Energy R&D**, with no additional funding for later-stage development, demonstration and deployment of solid-state lighting, HVAC, or transactive controls; a $28 million cut to research in HVAC and refrigeration technologies; a $23 million cut to building envelope research, including advanced envelope retrofit technologies; a $21.5 million cut to advanced LED and organic LED lighting research; and a $22 million cut to buildings-to-grid integration research.

ENDNOTES

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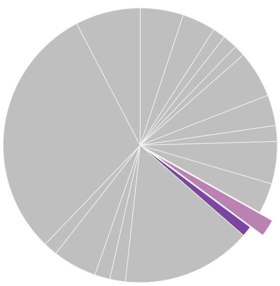
Federal Energy R&D: Grid Modernization

BY COLIN CUNLIFF AND BATT ODGEREL | MARCH 2020

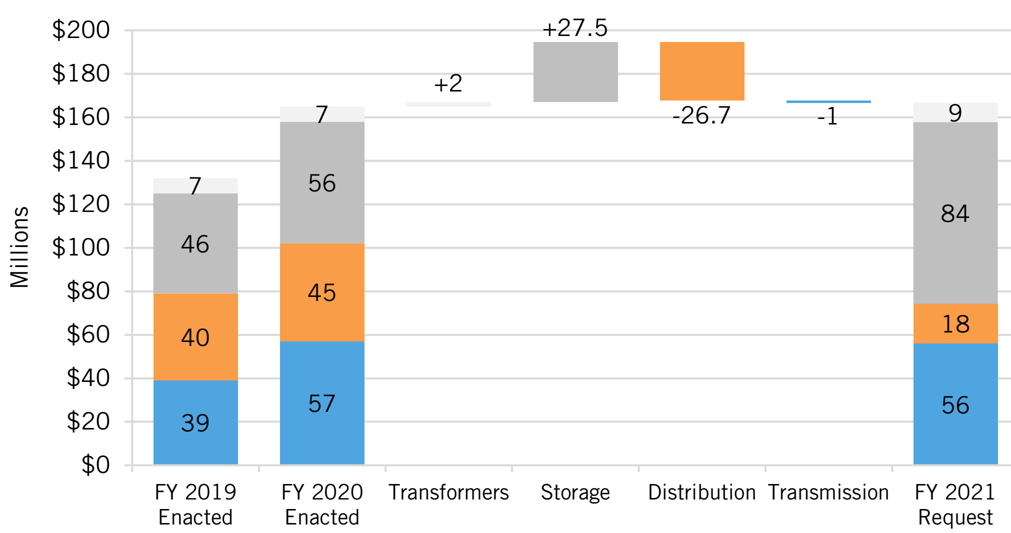
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



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

The grid modernization research and development (R&D) programs in the Office of Electricity (OE) accelerate discovery and innovation in electricity transmission, storage, 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 2021 budget request would increase grid modernization R&D by 1 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, the Department of Energy (DOE) established the Grid Modernization Initiative (GMI) 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) was created, which industry and government should jointly pursue to establish a resilient, secure, sustainable, and reliable grid.[4] For its part, DOE has set targets and performance measures in reliability and resilience, as well as cost and performance targets for new grid storage technologies.[5] In its latest round of funding in November 2019, DOE's GMI selected 23 projects at the national labs to receive $80 million over the next 3 years across topic areas ranging from resilience modeling to energy storage and system flexibility.[6]

DOE has also been ramping up its work in grid-scale energy storage. In the last budget cycle, it included a proposal to build a Grid Storage Launchpad at the Pacific Northwest National Laboratory (PNNL) to enable development, testing, and evaluation of batteries and other storage technologies for grid applications.[7] ITIF analysis has found that energy storage can enable better energy systems integration, and may be essential to incorporating greater shares of electricity from variable wind and solar.[8]

Grid Modernization R&D Subprograms

Grid modernization R&D is made up of four main subprograms:[9]

- **Transmission Reliability and Resilience (TRR)** focuses on ensuring the reliability and resilience of the 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 2021 Budget Proposal[10]

- **A 59 percent reduction in Resilient Distribution Systems,** with reduced funding for the development of GridAPPS-D™, an open-source advanced distribution management system application platform that provides utilities with a standardized environment to develop and test grid applications; reduced funding for other Advanced Distribution Management Systems (ADMS) research; no new funding for the National Test Bed Laboratory for Coordinated Management of

Microgrids and Networked Distributed Energy Resources (COMMANDER); and reduced funding for the Situational Awareness Network (SAN).

- **A 49 percent increase in Energy Storage,** primarily due to a $39 million boost for construction of the Grid Storage Launchpad at PNNL. Funding for other research activities in this subprogram would be cut by $11.5 million, with the focus on deployment and validation of longer-term (6 or more hours) storage systems for defense infrastructure; deployment of energy storage systems for cooperatives; and R&D on lead-acid batteries for grid storage applications.

- **A 2 percent decrease in Transmission Reliability and Resilience,** including reduced funding for development of the North American Energy Resiliency Model, an integrated energy system model to improve planning and contingency analyses that address energy system vulnerabilities; reduced funding for synchrophasor-specific tools and technologies; no new funding for the Center for Ultra-Wide-Area Resilient Electric Energy Transmission Networks (CURENT), an engineering research center at the University of Tennessee; and flat funding for the remainder of the programs, including research in protective relaying, research on data uncertainty, and development of algorithms of reliability and resilience.

- **A 29 percent increase in Transformer Resilience and Advanced Components**, including an additional $2 million to expand R&D on solid-state power substations (SSPS)—which off the potential of greater standardization and improved resilience of grid components and systems—with a focus on developing modeling and testing capabilities, and establishing a consortium to lead SSPS technology development efforts.

ENDNOTES

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ACKNOWLEDGMENTS

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ABOUT ITIF

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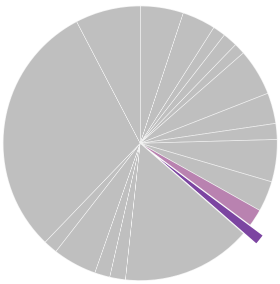
Federal Energy R&D:
Cybersecurity for Energy Systems

BY COLIN CUNLIFF AND BATT ODGEREL | MARCH 2020

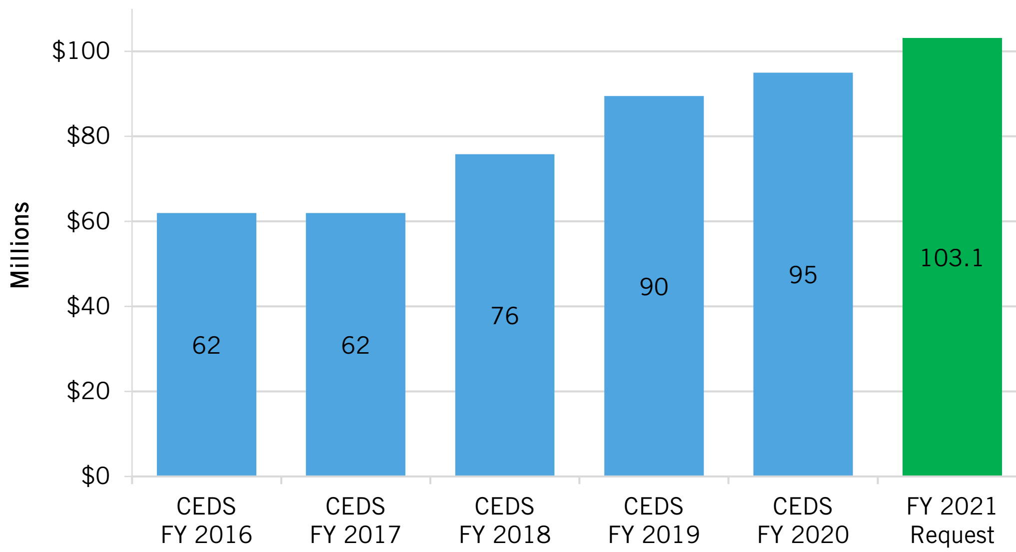
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



Cyber (purple)
Electricity TS&D (light purple)
Energy R&D (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 and mitigate vulnerabilities.[1]

Figure 1: The FY 2021 budget request would increase funding for CEDS R&D by 9 percent[2]



What's at Stake

The energy sector has in recent years been subjected to a dramatic increase in focused cyber probes, data exfiltration, and malware attacks. 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 operational 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, to steal data on several generation facilities.[4] And in March 2019, DOE reported that several counties in California, Utah, and Wyoming experienced a cyber event that caused interruptions of electrical system operations, marking the first successful cyberattack disrupting U.S. grid operations.[5]

The White House released the *National Cyber Strategy of the United States* in September 2018 to help federal agencies coordinate efforts, define roles and responsibilities, and prioritize cybersecurity efforts.[6] In June 2019, the Senate Energy and Natural Resources committee approved the Securing Energy Infrastructure Act to remove vulnerabilities in digital software systems hackers could exploit to access the energy grid.[7] 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.[8] The cybersecurity landscape is characterized by rapidly evolving threats and vulnerabilities juxtaposed against grid modernization and the convergence of utility OT and IT systems. Additional research, development, and demonstration (RD&D) is needed to work with industry partners to create cyberthreat detection, prevention, and mitigation tools for energy delivery systems.

Cybersecurity R&D Activities

In FY 2020, CEDS focused on these key research activities:[9]

- **Cyber Analytic Tools and Techniques™ 2.0 (CATT™ 2.0)** provides situational awareness and actionable information to support discovery and mitigation of cyber threats to the United States' energy infrastructure and operational technology environment, with classified threat information owned by the U.S. Government.

- **Cybersecurity for Operational Technology Environments (CyOTE™)** supports demonstration of data sharing and analysis in the OT environment to help utilities address the challenges of collecting data on OT networks.

- **Cybersecurity Risk Information Sharing Program (CRISP)** is a public-private partnership between DOE and energy-sector partners to facilitate the timely bidirectional sharing of unclassified and classified threat information, and develop situational awareness tools that enhance the sector's ability to identify, prioritize, and coordinate the protection of critical infrastructure.

- **Cybersecurity Capability Maturity Model (C2M2)** helps private-sector owners and operators better evaluate their cybersecurity capabilities, and prioritize and improve their cybersecurity activities.

Key Elements of the FY 2021 Budget Proposal

The Cybersecurity, Energy Security, and Emergency Response (CESER) office houses the 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:[10]

- Continued funding for the Advanced Threat Mitigation initiatives supporting existing cybersecurity projects, including CATT™, CyOTE™, and C2M2.

- New funding of $22 million to develop cybersecurity solutions for the next generation of advanced tools and technologies.

- New funding of $12.1 million for demonstration of cybersecurity solutions for energy systems that support military and government installations.

- No additional funding for two FY 2020 congressionally directed programs: DarkNet project, which is focused on optical fibers and communication technologies, and Consequence-driven Cyber-informed Engineering project, which supports consequence prioritization processes to simplify and isolate automated systems; and no additional funding for advanced cyber and cyber-physical solutions for distribution and municipal utilities.

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Federal Energy R&D: Nuclear Energy

BY COLIN CUNLIFF AND BATT ODGEREL | MARCH 2020

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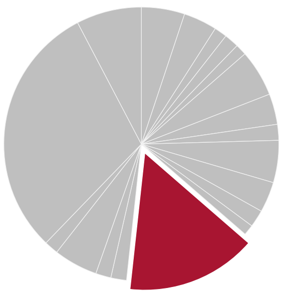
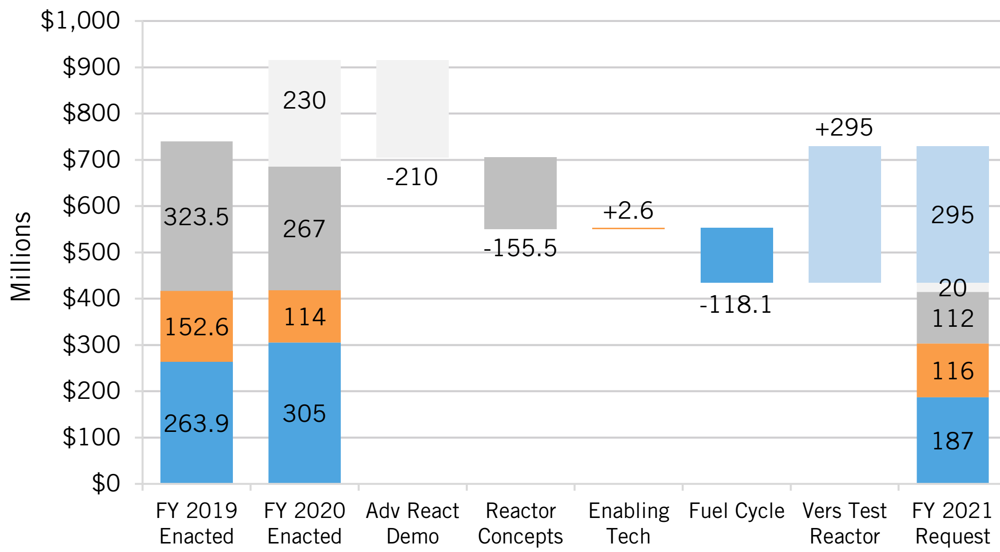


Nuclear Energy R&D (red)
Energy R&D (gray)

Nuclear power accounts for 19 percent of the electricity generated in the United States, and 53 percent of all carbon-free electricity, more than hydro and renewables combined.[1] Despite this success, the existing nuclear fleet is being challenged by low-cost natural gas and renewables, at the same time 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 research and development (R&D) on the 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 2021 budget request would cut nuclear energy R&D by 21 percent



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 September 2020, with the first SMR module expected to begin operating in 2026.[4]

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 heat for the chemicals industry), 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.[5]

Recent action in Congress and by the administration aims to jump-start innovation in advanced nuclear technologies. In the FY 2019, the administration proposed a new R&D subprogram focused on advanced (non-light-water) SMRs, which Congress funded at $100 million. And in the FY 2020 budget cycle, Congress established a new Advanced Reactor Demonstration subprogram to build and demonstrate two advanced reactor designs by the mid-2020s. Congress also passed the Nuclear Energy Innovation Capabilities Act in September 2018 to facilitate private-sector innovation in advanced reactor technologies.[6] And in July 2019, the Senate Committee on Energy and Natural Resources approved the bipartisan Nuclear Energy Leadership Act to refocus DOE's nuclear energy research programs, establish a domestic supply of advanced reactor fuel, enable first-of-a-kind deployment of new nuclear technologies, and build a Versatile Test Reactor.[7] But these efforts are jeopardized without greater levels of sustained funding for nuclear energy R&D and pilot and demonstration projects to prove out designs at commercial scale.

Nuclear Energy R&D Subprograms

In FY 2020, NE conducted R&D in the following subprograms:[8]

- **Reactor Concepts RD&D** (research, development, and demonstration) focuses on new and advanced reactor designs and technologies, including advanced SMRs, fast reactors using liquid-metal coolants, high-temperature reactors, and micro-reactor technologies.

- **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.

- **Advanced Reactor Demonstration** is a new subprogram established by Congress in FY 2020 to build and demonstrate two advanced reactor designs within the next 5 to 7 years.

- **Supercritical Transformation Electric Power (STEP) and other NE R&D** (not shown in figure 1) include R&D on supercritical carbon dioxide Brayton-cycle technologies (which are potentially applicable to all steam electric generation), as well as nuclear-workforce training and education programs.

Key Elements of the FY 2021 Budget Proposal

- **New funding to begin construction of the Versatile Test Reactor (VTR),** a user facility that will enable testing of materials and fuel designs common to many advanced, non-light-water-reactor designs.[9]

- **A 91 percent cut to the Advanced Reactor Demonstration Program,** including the elimination of funding for two advanced reactor demonstration projects; no new funding for risk reduction for future demonstrations; a $10 million cut to the National Reactor Innovation Center; and a $10 million cut to regulatory development and advanced reactor safeguards research.

- **A 58 percent reduction in Reactor Concepts R&D**, including a $90 million cut to advanced small modular reactor R&D; a $16.5 million cut to light-water-reactor sustainability R&D; and a $16 million boost to advanced reactor technologies development. The VTR would be moved out of Reactor Concepts and into its own subprogram.

- **A 39 percent reduction in Fuel Cycle R&D**, including reduced funding for accident-tolerant fuels, advanced nuclear fuels, material recovery and waste-form development, and used nuclear fuel disposition R&D, as well as the elimination of integrated waste management activities. Funding to support the development and testing of Tri-structural isotropic (TRISO) fuel—which is more resistant to irradiation, corrosion, and high temperatures than traditional nuclear fuels—would receive a slight boost.

- **A 2 percent increase in Nuclear Energy Enabling Technologies**, including reductions in advanced modeling and simulation and nuclear science user facilities; and small increases in cross-cutting technology development and the Transformational Challenge Reactor program.

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

ENDNOTES

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Federal Energy R&D: Carbon Capture

BY COLIN CUNLIFF AND BATT ODGEREL | MARCH 2020

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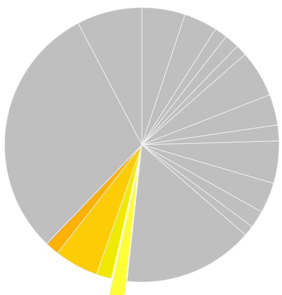
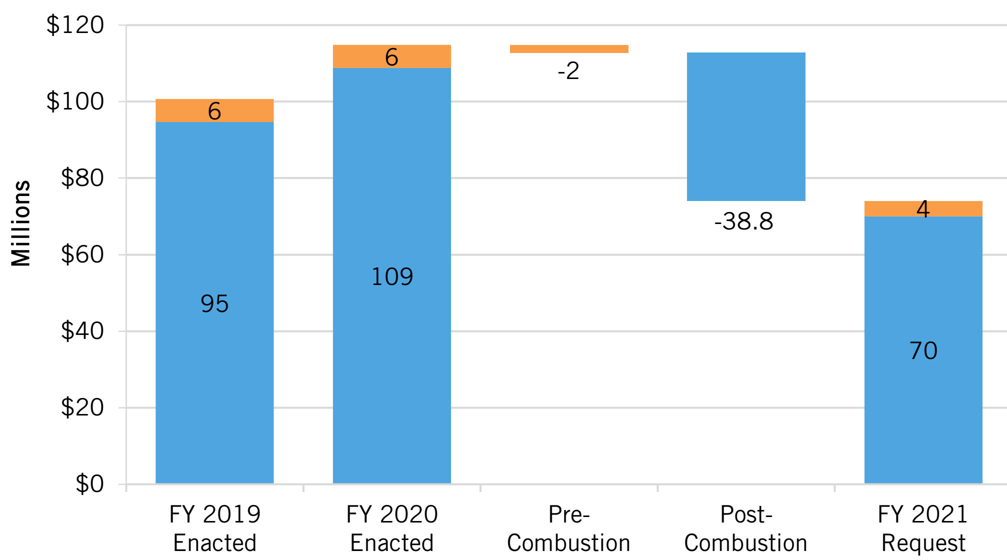


Carbon Capture (bright yellow)
Other Fossil (shades of yellow)
Energy R&D (gray)

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 currently exist.[1] The 2018 Intergovernmental Panel on Climate Change (IPCC) special report on 1.5°C of warming found that CCUS plays an essential role in nearly all deep decarbonization pathways.[2] The Department of Energy's (DOE) carbon-capture research, development, and demonstration (RD&D) program focuses on two complementary technologies: pre-combustion systems, in which coal is gasified and the carbon dioxide (CO_2) removed 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 2021 budget request would cut carbon capture R&D by 36 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-fuel demonstration began operating at the NET Power facility in Texas in May 2018, and the company is targeting 2020 to commercially deploy a 300-megawatt project using a supercritical CO_2 cycle.[6] The National Carbon Capture Center in Wilsonville, Alabama, is now installing a natural-gas-fired system to test technologies under natural-gas-fired and coal-fired flue gas conditions.[7] And in February 2018, Congress expanded and extended the 45Q tax credit to incentivize greater utilization and storage of captured CO_2.[8]

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.[9]

DOE's carbon capture program has primarily focused on coal-fired power plants, to the exclusion of natural gas power plants and industrial sources. The ICCS program, which explored both power plant and industrial applications of carbon capture, received a one-time appropriation through the American Recovery and Reinvestment Act of 2009 (ARRA), but has received no further funds.[10] This focus leaves the unique challenges of integrating and optimizing carbon capture with other sources of emissions unsolved. ITIF recommends DOE establish new carbon capture programs for natural gas power plants and industrial facilities.[11] ITIF has also called for the federal government to invest in a robust portfolio of demonstration projects, which would include major investments in CCUS.[12] In FY 2020, Congress for the first time directed DOE to reserve $4 million "for research and optimization of carbon capture technologies for use at industrial facilities," and $7 million for carbon capture at natural gas power plants.[13]

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.[14] Additionally, DOE has sought to establish international leadership in CCUS technologies through its participation in the Clean Energy Ministerial and Mission Innovation.[15] 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. These systems 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.[16]

- **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 and highly concentrated CO_2, with the former used for energy storage and fuel, and the latter captured and sequestered.

Activities within the carbon capture program are tightly coupled with research and development (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., Allam cycles), are all designed and optimized to integrate with carbon capture technologies.[17]

Key Elements of the FY 2021 Budget Proposal

- **A 36 percent reduction in Post-Combustion Capture Systems**, including a shift away from later-stage R&D and demonstration projects. The budget proposes focusing on early-stage research on novel CO_2 separation technologies, including non-aqueous solvents, membranes, advanced sorbents, and cryogenic processes. This subprogram would also support early-stage testing of negative emissions technologies, including direct air capture (DAC) and bioenergy with carbon capture and storage (BECCS).

- **A 33 percent reduction in Pre-Combustion Capture Systems,** including a shift away from later-stage R&D. No funding is requested for activities to scale up pre-combustion technologies beyond bench-scale demonstrations.

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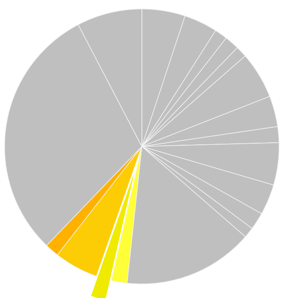
Federal Energy R&D: Carbon Storage and Utilization

BY COLIN CUNLIFF AND BATT ODGEREL | MARCH 2020

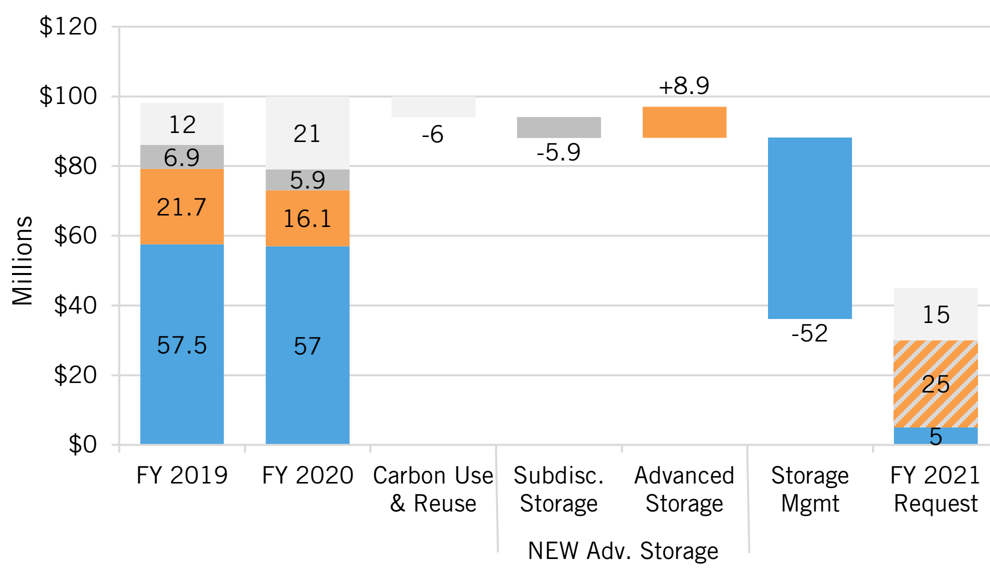
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



Carbon Storage (dark yellow)
Other Fossil (shades of yellow)
Energy R&D (gray)

The Carbon Storage and Utilization programs are focused on the development of technologies for the safe use and permanent storage of captured carbon dioxide (CO_2). The storage program focuses on developing the technologies and infrastructure necessary to store captured CO_2 safely in deep saline formations or oil and natural gas reservoirs.[1] The carbon use and reuse program focuses on recycling captured CO_2 into valuable products, such as chemicals, fuels, and building materials.

Figure 1: The FY 2021 budget request would cut carbon storage and utilization R&D by 55 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. Research and development (R&D) is also needed for 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 CO_2 is safely and permanently stored.

In April 2017, the Illinois Industrial Carbon Capture and Storage project—funded jointly by the Department of Energy (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 could store more than 50 million metric tons of CO_2 as part of its Carbon Storage Assurance Facility Enterprise (CarbonSAFE) initiative.[5] The proposed budget would substantially cut funding for these efforts.

Carbon utilization—turning CO_2 from a waste product into a product of value—is key to expanding the market for CO_2 and incenting greater carbon capture. But many potential uses for captured carbon, such as carbon nanotubes and synthetic hydrocarbon fuels, are far from commercialized, and require further R&D in order to bring costs down. In 2019, the National Academies developed a broad innovation agenda for chemical and biological conversion of CO_2 into fuels and chemicals, but funding at DOE has been insufficient to address the full suite of research, development, and demonstration needs identified by the National Academies.[6]

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 CarbonSAFE initiative, which funds industry cost-shared R&D projects to characterize and develop commercial-scale (more than 50 million metric tons 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.[7]

- **Advanced Storage R&D** is focused on 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.

- **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. The budget request proposes merging the subprogram with Advanced Storage R&D.[8]

- **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 carbon capture, utilization, and sequestration (CCUS) through the creation of value-added products via the conversion of CO_2.

Key Elements of the FY 2021 Budget Proposal

- **A 91 percent reduction in Storage Infrastructure R&D,** and no funding for activities other than "infrastructure network studies and cost and performance analyses." It is unclear whether the CarbonSAFE Initiative, 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 CO_2 is safely and permanently stored.

- **A 14 percent increase in Advanced Storage R&D** (which would be merged with Sub-disciplinary Storage R&D), with the increased funding focused on efforts to advance machine learning/artificial intelligence (ML/AI) tools to support subsurface storage decision-making.

- **A 29 percent reduction in Carbon Use & Reuse R&D,** with reduced funding supporting laboratory- and bench-scale activities to convert CO_2 into chemicals, building materials, and solid carbon.

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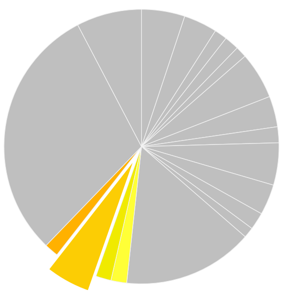
Federal Energy R&D: Advanced Coal Energy Systems

BY COLIN CUNLIFF AND BATT ODGEREL | MARCH 2020

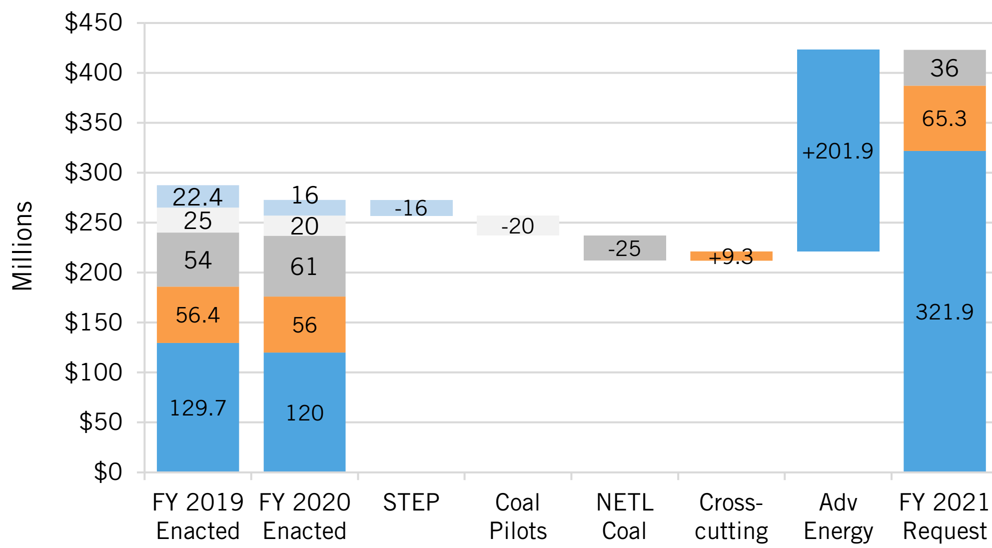


Adv Coal (orange)
Other Fossil (yellow)
Energy R&D (gray)

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

The Department of Energy's (DOE) Advanced Coal Energy Systems research and development (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 2021 budget request would increase Advanced Coal Energy Systems R&D by 68 percent[2]



What's at Stake

Coal currently accounts for 24 percent of U.S. electricity generation and 60 percent of power-sector carbon emissions.[3] Coal-fired generation is projected to decline through the mid-2020s, although it is projected to remain a significant part of the nation's energy mix for decades to come.[4]

Some Advanced Coal Energy Systems R&D projects are designed and intended to integrate with carbon capture technologies, which would enable the continued use of coal in low-carbon energy systems. For example, gasification systems combine coal with oxygen and steam under high pressure to produce a hydrogen and carbon dioxide (CO_2) gas mixture. The CO_2 can be separated prior to combustion, and the remaining hydrogen combusted in a combined-cycle power plant.[5] Similarly, solid oxide fuel cells (SOFCs) convert gasified coal into electricity without combustion, and produce highly concentrated CO_2 streams that enable low-cost carbon capture.[6] Additional research, development, and demonstration (RD&D) of SOFCs and gasification systems integrated with carbon capture is necessary to lower costs and sufficiently improve performance to enable commercial deployment. But these programs are targeted for the largest cuts.

The bulk of funding in the Advanced Coal Energy Systems programs supports the administration's Coal FIRST (Flexible, Innovative, Resilient, Small, Transformative) initiative to improve the economics of coal-fired electricity generation and develop the next generation of high-efficiency coal plants. In February 2020, DOE announced $64 million in federal funding for R&D to develop advanced combustion technologies, supercritical CO_2 systems, and other coal technologies.[7] But without integration with carbon capture, utilization, and storage (CCUS), 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:[8]

- **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-megawatt (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 applications for nuclear, gas, and concentrating solar as well as coal power plants.[9]

- **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.[10]

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

Key Elements of the FY 2021 Budget Proposal[11]

- **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 168-percent increase in Advanced Energy Systems**, with $182.5 million in increased funding for power-generation efficiency to support the Coal FIRST initiative; and a $20 million increase to support advanced coal processing to convert coal to carbon fiber, nanomaterials, building materials, and other value-added products. Funding for advanced sensors and controls and advanced energy materials would receive small increases. Funding for advanced turbines, gasification systems, and solid oxide fuel cells would be cut by 66 percent.

- **A 17-percent increase in Cross-Cutting Research,** including increased funding for R&D to support critical and rare-earth minerals extraction from coal and coal waste products; increased funding for modeling and simulation to optimize coal power plants; decreased funding for water management R&D field testing; and reduced funding for university training and research.

- **No new funding for the Transformational Coal Pilots program.** The Consolidated Appropriations Act of 2017 provided $50 million for new coal pilots to remain available until expended, and the remainder of FY 2020 funding will be used for at least one Phase III construction/operation award.

- **A discontinuation of funding for STEP,** as prior-year appropriations have fully funded the STEP pilot's CO_2 test facility, now under construction in San Antonio, Texas—and the administration has not announced any plans for follow-on work.

- **A small decrease to NETL Coal R&D.** The $23 million research activity on rare-earth elements recovery from coal by-products would be moved to the Cross-Cutting Research subprogram, but would not be eliminated. The remaining NETL Coal R&D subprogram would receive a small $2 million cut, reflecting a deferral of research equipment purchase.

ENDNOTES

1. U.S. Department of Energy (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 2021 Congressional Budget Justification," Volume 3 Part 2, 207–244 (DOE Chief Financial Officer, DOE/CF-0164, February 2020), https://www.energy.gov/sites/prod/files/2020/02/f72/doe-fy2021-budget-volume-3-part-2_2.pdf.
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Federal Energy R&D: Oil & Gas

BY COLIN CUNLIFF AND BATT ODGEREL | MARCH 2020

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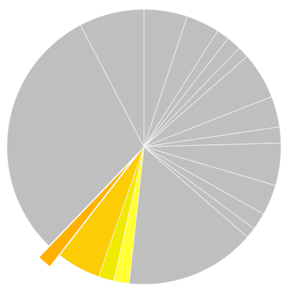
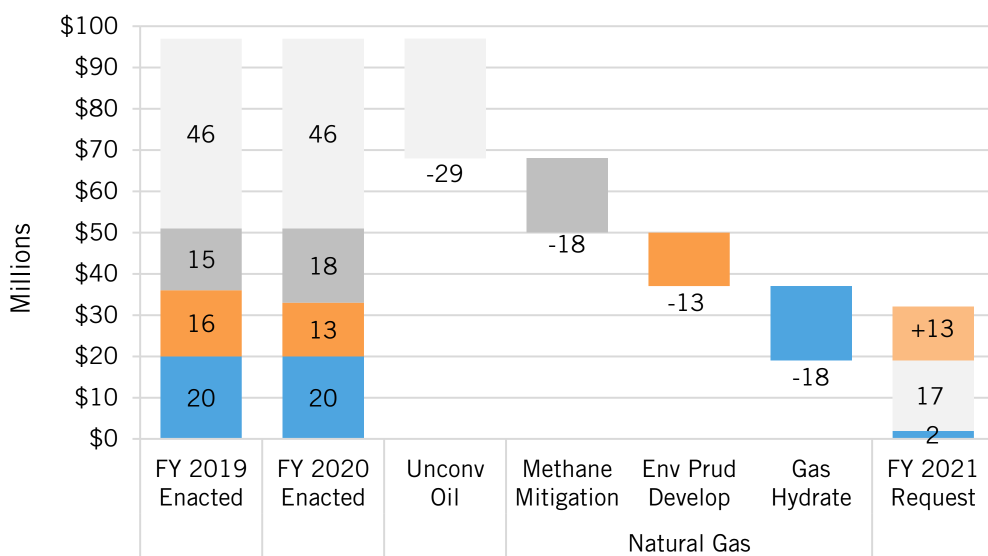


Oil & Gas (orange)
Other Fossil (yellow)
Energy R&D (gray)

The Department of Energy's (DOE) oil and natural gas program supports research and development (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 coproduced 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 2021 budget request would reduce oil and gas R&D by 67 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 fugitive methane emissions 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. 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 (CO_2), although its atmospheric residence time is much shorter.[3] Reducing methane emissions would have the dual effect of improving the environmental performance of natural gas systems and enhancing stewardship of domestic gas resources. Additional R&D activities include treating and managing coproduced water, characterizing and minimizing induced seismic risk, and reducing surface footprints on well-pad sites and surrounding areas.[4] 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.[5]

Oil & Gas R&D Activities

R&D in oil and natural gas is spread among four activities:[6]

- **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** focus on technologies that quantify and reduce methane leaks and vented emissions from natural gas systems. Methane is the second-largest driver of climate change (behind only CO_2), 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 activities 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 more gas makes its way to the consumer; and reduce the greenhouse gas emissions that cause climate change.
- **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 advance 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 2021 Budget Proposal[9]

- **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.

- **Elimination of the Environmentally Prudent Development program,** which would hinder efforts to mitigate the environmental impacts of natural gas production.

- **Creation of a new $13 million Natural Gas Infrastructure Research program** (light orange in the FY 2021 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. The proposed funding level and research activities do not provide an adequate substitute for the methane emissions quantification and mitigation programs or the environmentally prudent development program.

- **A 90 percent reduction in Gas Hydrates research.**

- **A 63 percent reduction in Unconventional Oil R&D,** due to a focus on current field laboratory projects, with no additional field test sites, produced water treatment technology development, or offshore research budgeted in FY 2021.

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 ($13 million in FY 2021), shown in green on the FY 2021 Request column. DOE, "FY 2021 Congressional Budget Justification," Volume 3 Part 2, 198–199 and 245–257 (DOE Chief Financial Officers, DOE/CF-0164, February 2020), https://www.energy.gov/sites/prod/files/2020/02/f72/doe-fy2021-budget-volume-3-part-2_2.pdf.
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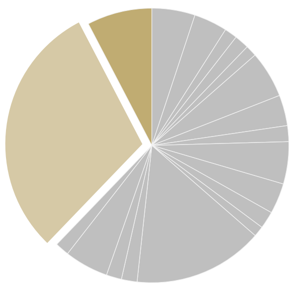
ABOUT ITIF

Federal Energy RD&D: Basic Energy Sciences

BY COLIN CUNLIFF AND BATT ODGEREL | MARCH 2020

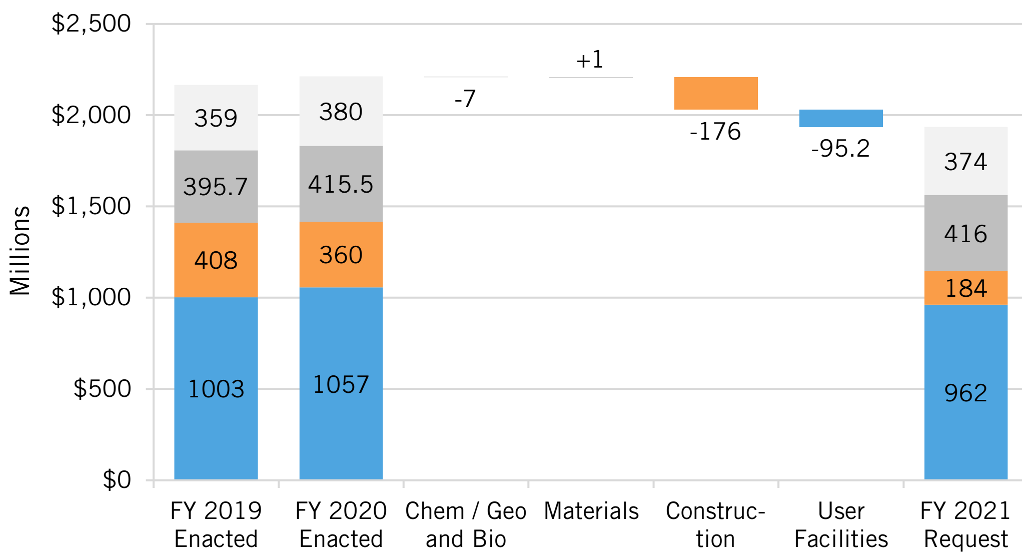
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



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

Basic Energy Sciences (BES) supports fundamental research into understanding, predicting, 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, conversion, 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 2021 budget request would cut basic energy sciences R&D by 13 percent[2]



What's at Risk

Research in BES is a key component of the energy innovation ecosystem, and comprises 27 percent of the energy research and development (R&D) budget. 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. Many have resulted in the commercialization of new technologies that shape the way we produce and consume energy—years, and often decades, later after the initial research was done.[3] The National Academy of Sciences has called for a doubling of basic science research, including BES, as a means of addressing challenges to U.S. competitiveness.[4] And House Republicans, led by Rep. Frank Lucas (R-

OK), put forward legislation in 2020 to double funding for BES to accelerate clean energy innovation over a ten-year period.[5]

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 Joint Center for Artificial Photosynthesis (i.e., solar fuels hub) at the California Institute of Technology, which seeks to generate fuels directly from sunlight, carbon dioxide, and water in a manner similar to natural photosynthesis; and the Joint Center for Energy Storage Research (i.e., batteries and energy storage hub) at Argonne National Laboratory, which researches nanoscale phenomena to develop next-generation, beyond-lithium-ion-energy storage systems. Annually, BES's 12 user facilities provided 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 nanoscale.[6]

Basic Energy Sciences R&D Activities

R&D in basic energy is distributed across four subprograms:[7]

- **Materials Sciences 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—5 light sources, 2 neutron scattering facilities, and 5 nanoscale science research centers—that provide thousands of researchers from universities, industry, and government laboratories unique tools to advance a wide range of scientific 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 development 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 2021 Budget Proposal[8]

- **Funding most BES User Facilities at "91 percent optimum,"** which means most light sources would only be operated for 91 percent of the total potential operating time. Additionally, both BES-supported neutron sources, the Spallation Neutron Source (SNS) and the High Flux Isotope Reactor (HFIR), would operate at 91 percent optimum. This means 860 fewer researchers would be able to use the BES user facilities than in FY 2020, and 2,670 potential research hours would be unused.

- **A 71 percent, or $17 million, 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.

- **A 50 percent cut to BES Construction,** including reduced funding for upgrades at the Advanced Photon Source, the Spallation Neutron Source, the Advanced Light Source, and the Linac Coherent Light Source-II.

- **Flat funding for the Batteries and Energy Storage innovation hub as well as the Fuels from Sunlight innovation hub.**

- **Near-flat funding for Materials Science and Engineering Research**. Scattering and instrumentation sciences research would get a $6 million cut; condensed matter and materials physics would get a $22 million boost; and materials discovery research would get a $2 million boost.

- **Near-flat funding for Chemical Sciences, Geosciences, and Biosciences.** Research in fundamental interactions would be cut by $2 million, and photochemistry and biochemistry by $8 million. Chemical transformations would get a $4 million boost; computational chemical sciences would receive flat funding.

ENDNOTES

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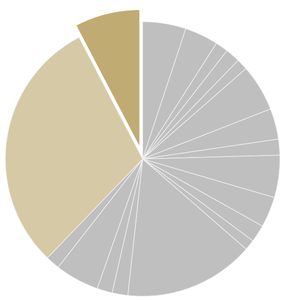
Federal Energy R&D: Fusion Energy Sciences

BY COLIN CUNLIFF AND BATT ODGEREL | MARCH 2020

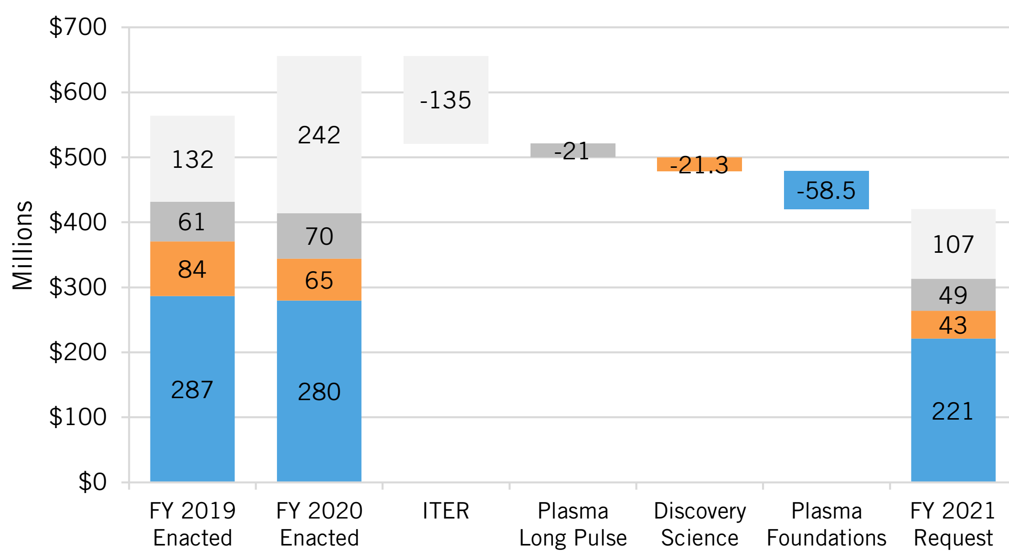
This briefing is part of a series on the U.S. energy budget. See: itif.org/energy-budget.



Fusion Energy (brown)
Basic Energy Science (dark 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.[2] 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 2021 budget request would cut fusion R&D by 37 percent[3]



What's at Risk

Fusion research and development (R&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 also 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.[4] 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:[5]

- **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. The United States contributes funding, personnel, and in-kind hardware components to the ITER facility currently under construction in France.

Key Elements of the FY 2021 Budget Proposal[6]

- **A 21 percent reduction in Basic Plasma Science: Foundations**, including a $27 million cut to research and operations at DIII-D, the largest magnetic fusion user facility in the United States; a $4 million cut to enabling R&D in high-temperature superconducting magnet technology and plasma fueling and heating technologies; 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. Theory and Simulation would get a boost of $7 million, most of which would go into Scientific Discovery through Advanced Computing (SciDAC) partnerships.
- **A 30 percent reduction in Basic Plasma Science: Long Pulse**, including a $6 million cut to long-pulse tokamak research, as well as a $14 million cut 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 33 percent reduction in Discovery Plasma Science,** including a $5 million cut in general plasma science, which explores low-temperature plasma science and engineering; and an $8 million cut in high energy density plasma science, which explores the behavior of matter at extreme conditions of temperature, density, and pressure.

- **A 56-percent reduced contribution to the International Thermonuclear Experimental Reactor (ITER).** ITER is the only mature burning plasma experiment in the world, and the National Academies has found that no single country has the expertise or the capacity to conduct a fusion experiment at this scale.[7] As a member of ITER, the United States has committed to provide 9 percent 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.[8] Reduced funding to ITER could jeopardize U.S. researchers' access to ITER technology and science.

- **A new pilot program called "Innovation Network for Fusion Energy" (INFUSE),** which aims to accelerate progress in fusion energy by establishing research partnerships with the private sector. Modeled after the successful Gateway for Accelerated Innovation in Nuclear (GAIN) Energy Voucher program, the INFUSE program provides private-sector fusion companies with access to the expertise and facilities of the Department of Energy's national laboratories.

ENDNOTES

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