Energizing Innovation: Raising the Ambition for Federal Energy RD&D in Fiscal Year 2022

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The United States should launch a "moon shot" in clean energy that mobilizes its unmatched innovative capabilities to combat climate change and capture global markets. The fiscal year 2022 budget is a critical opportunity for Congress to advance U.S. energy innovation.

KEY TAKEAWAYS

- In December, Congress provided a sweeping bipartisan overhaul of innovation programs in the Energy Act of 2020, paving the way for a major expansion in federal energy RD&D investments to combat climate change and strengthen U.S. competitiveness.
- The Biden administration has now proposed a 27 percent boost in RD&D appropriations for the Department of Energy for FY 2022—and a quadrupling of government-wide clean energy RD&D spending over the next four years.
- This boost responds to the real possibility U.S. companies and workers will be left behind as other nations, including China, Japan, and EU members race ahead to develop clean technologies. China has doubled its energy RD&D in just five years.
- Congress and the administration should seize the momentum created by the Energy Act by providing a multi-billion-dollar increase in clean energy innovation investment in FY 2022.

INTRODUCTION

The fiscal year (FY) 2022 budget is a critical opportunity for Congress and the administration to rapidly scale up U.S. investment in energy innovation. In December, Congress provided a sweeping bipartisan overhaul of federal energy innovation programs in the Energy Act of 2020, paving the way for a major expansion in federal research, development, and demonstration (RD&D) to combat climate change and strengthen U.S. competitiveness. And members of Congress on both sides of the aisle have called for reinvigorating the national energy innovation system in order to reverse decades of declining investments and position the United States to thrive in a global clean energy transition. The Biden administration has followed suit, proposing a 27 percent boost in energy RD&D at the Department of Energy (DOE) in FY 2022 and a quadrupling of government-wide clean energy RD&D over the next four years.

But other nations such as Japan, China, and those within the European Union are investing more in energy RD&D to develop carbon-free technologies and capture growing global clean energy markets. China has doubled its energy RD&D in just the last five years, and now invests more than the United States does in key technologies, including solar energy, lithium-ion batteries, advanced nuclear, carbon capture, and electric vehicles (EVs).[1] Europe is outstripping the United States in offshore wind, and has set aggressive targets in hydrogen and low-carbon steel. Meanwhile, U.S. investment in RD&D has declined to its lowest level since pre-Sputnik.[2] And U.S. companies account for a declining share of new cleantech patents, indicating the United States is falling behind in innovation.[3]

The United States should launch a "moon shot" in clean energy that mobilizes the nation's unmatched innovative capabilities to meet the climate challenge and capture global markets. Congress and the administration should seize on the momentum created by the passage of the Energy Act of 2020, and provide a multi-billion-dollar increase in energy innovation programs at DOE in its FY 2022 budget.

Last year, the Information Technology and Information Foundation (ITIF) partnered with Columbia University's Center on Global Energy Policy (CGEP) to produce *Energizing America: A Roadmap to Launch a National Energy Innovation Mission.* This landmark volume calls on policymakers to triple investment in energy RD&D over five years, develops strategic principles for balancing the portfolio, and provides targeted recommendations for accelerating innovation across key decarbonization challenges.

This report builds on *Energizing America* and consolidates ITIF analysis of federal energy innovation programs and its recommendations to accelerate critical energy technologies. The summary herein provides an overview of federal energy innovation programs, including the key role of DOE in advancing energy technologies and the department's impact on national energy systems. It assesses the significant updates to DOE's program authorizations made in the Energy Act and the prospects for greater investment in the FY 2022 budget and appropriations cycle.

Companion to the summary herein are 21 short policy briefs that span DOE's RD&D programs in renewable energy, transportation, energy efficiency, grid modernization, nuclear energy, fossil energy and carbon management, and basic sciences. Each brief includes a description of the DOE's program and technology goals; what's at stake and potential impacts of the program; historic and authorized funding levels; and targeted recommendations for Congress and DOE to accelerate innovation.

This report also includes a living interactive data visualization that will be updated throughout the FY 2022 budget cycle. The administration is expected to release the full congressional budget justification in late Spring 2021, and House and Senate proposals will soon follow. The interactive data visualization will provide a resource for policymakers, researchers, and the public to track federal investments in energy innovation.

INNOVATION IS ESSENTIAL TO ADDRESS CLIMATE CHANGE AND BOOST U.S. COMPETITIVENESS

The transition from an energy system dominated by unabated fossil fuels to one with net-zero emissions is critical for mitigating climate change, protecting human health, and revitalizing the U.S. economy. However, clean energy alternatives have not yet been commercialized for some of the sectors that produce large amounts of greenhouse emissions, including aviation, shipping, steel, cement, and chemicals manufacturing. Meanwhile, many of the clean technologies that already have been commercialized—such as EVs—are still more expensive than the emitting technologies they would replace, and also face other barriers to scaling up. These costs and barriers must continue to fall for these clean technologies to cut emissions drastically.

The transition also brings with it risks and opportunities for U.S. industry. Investment in key clean technologies—from hydrogen to EVs to batteries to carbon capture and storage (CCS)—is rapidly increasing around the world. Even during the COVID-19 pandemic, when many traditional energy industries have suffered from delayed or declining investment, global investment in clean energy has increased. A key question for policymakers is whether that investment will occur in the United States or elsewhere. The risk lies in being left behind as other nations capture growing global sectors.

The solution to both of these challenges is to boost U.S. investment in innovation. But accelerating innovation requires assertive federal policy that involves more than basic research funding. Innovation requires both proactive public investment in RD&D and the creation of markets to hasten early adoption and ignite private sector innovation and competition.

Innovation to Drive Economic Growth and Capture Growing Global Markets

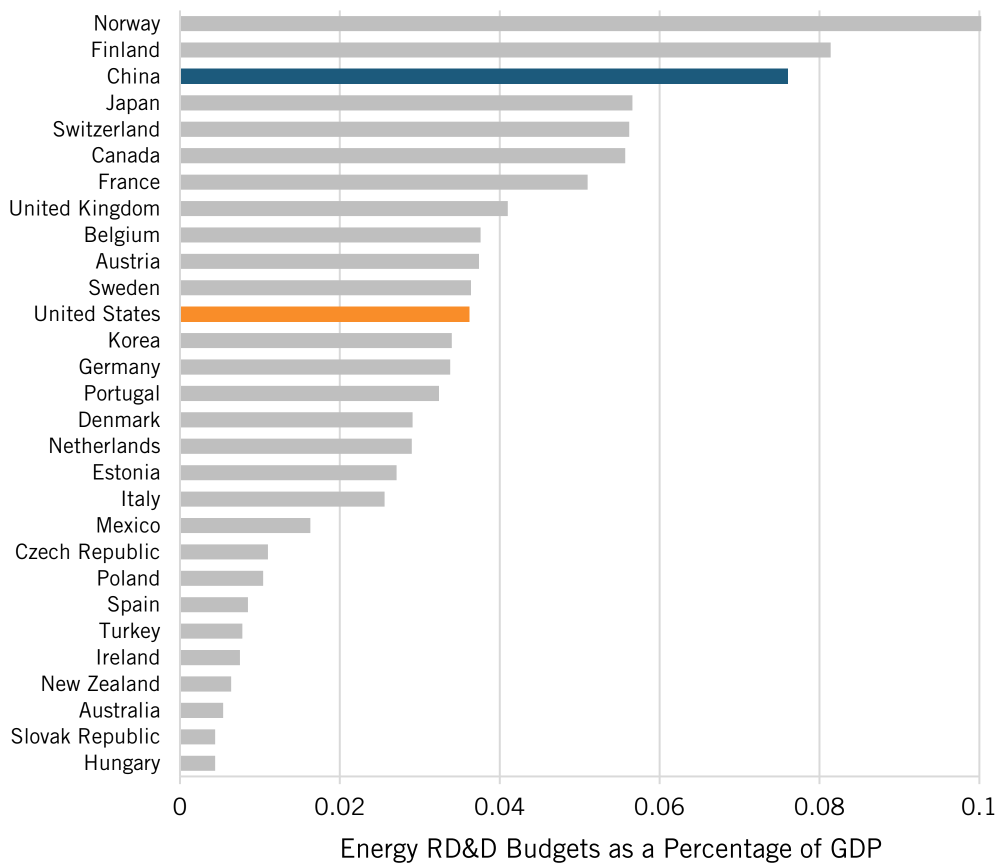
Innovation is fundamental to both long-term job creation in the U.S. economy and the resilience of the economy to disruptions. Technology discovery and development create opportunities for new jobs, and innovation in established technologies drives long-term cost reductions and improvements in quality. Innovation is also an important engine for entrepreneurship, especially in tech-heavy sectors. Finally, innovation is a necessary condition, albeit an insufficient one, for U.S. competitiveness in the rapidly growing global clean energy industry.[4]

Global annual investment in energy was $1.5 trillion in 2020, a decline of 20 percent from 2019 levels due to the COVID-19 pandemic.[5] But the share going to clean energy has been increasing in spite of those headwinds. Investment in renewable energy grew 2 percent in 2020 to $304 billion. Investment in EVs surged to $139 billion in 2020, beating the previous year by 28 percent despite the pandemic.[6] Significant economic opportunities await countries that can supply new and growing clean energy markets.

The United States has long been the world's leading technological innovator, but it has not always effectively used this advantage to sustain domestic manufacturing.[7] For example, scientists at Bell Labs in New Jersey created the first solar cell in 1957, and strong and steady procurement from the Navy and NASA allowed American solar companies to serve the market in that technology's early days.[8] Since the turn of the century, however, the United States has ceded much of its original leadership. Only one of the top 10 solar photovoltaic (PV) manufacturers, First Solar, is an American firm (eight are Chinese, one is South Korean), and U.S. companies' share of the global solar market has dropped below 10 percent.[9]

As countries around the world seek to stimulate their economies and recover from the COVID-19 crisis, the United States could fall further behind in a range of technology areas. The European Union announced more than $200 billion in climate-friendly economic recovery investments, such as clean hydrogen infrastructure.[10] The Chinese government has announced a "new infrastructure" package worth $1.4 trillion that will include investments in advanced energy industries and infrastructure. Japan, the European Union, and 11 other nations have launched national hydrogen strategies and are investing heavily in electrolyzers, fuel cells, and other hydrogen technologies.[11]

Figure 1: Government energy RD&D investment as a percentage of gross domestic product (GDP), 2019



Even in public funding for energy RD&D, an area wherein the United States has long been the top investor, U.S. leadership is now being challenged by China and Europe. China doubled its investment in clean energy RD&D between 2015 and 2020 to $8 billion annually, putting it ahead of the United States in absolute spending for the first time.[12] And 11 other countries invest more in energy RD&D as a share of their economies than does the United States (figure 1).[13] 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—from roughly 50 percent in 2001 to less than 40 percent in 2016—has declined, indicating that U.S. leadership in innovation truly is waning.[14]

These trends are disturbing. The decline of the U.S. manufacturing sector has cost the economy high-quality jobs, increased income inequality, and contributed to public dissatisfaction. The National Academies' report *Accelerating Decarbonization of the U.S. Energy System* argues that "the United States should attempt to claw these industrial sectors and markets back, so that it leads the world both in innovation and in the manufacturing and marketing of advanced clean energy technologies."[15]

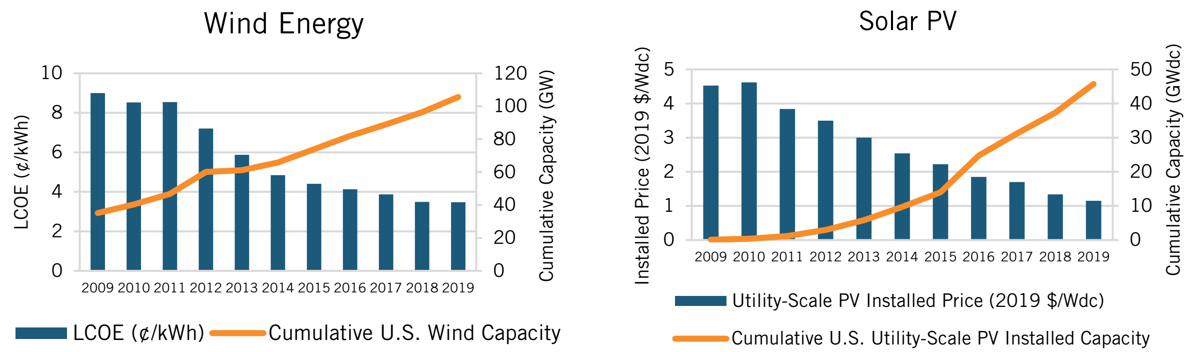
But the Academies find cause for optimism. The United States has rich natural resources that give it a competitive advantage in the clean energy transition: It has abundant solar and wind resources (both onshore and offshore), 40 million acres already devoted to producing biofuels, plentiful natural gas, and enormous geologic and terrestrial reservoirs for carbon dioxide (CO_2) sequestration. The challenge will be to combine these natural assets with the nation's culture of innovation to regain global leadership and competitiveness in clean energy technology, modernize and transform the U.S. manufacturing base, and create a new generation of clean energy jobs.[16]

Innovation to Combat Climate Change

Decarbonizing the U.S. economy by 2050 is technically feasible, provided that adequate investments are made over the next decade to advance critical clean energy technologies and solutions.[17] But current funding levels are not sufficient to generate the pace of innovation needed to address climate change. According to the International Energy Agency (IEA), only 6 out of 46 critical energy technologies are "on track" to achieve a net-zero emissions energy system.[18]

The energy innovation agenda of the last 10 years focused, with considerable success, on reducing the cost and expanding the use of wind and solar resources for electricity generation (figure 2). Rapid cost declines in solar PV, wind turbines, and grid-scale batteries are enabling decarbonization of the power sector on a much faster timeframe than was imagined a decade ago.[19] As of 2018, wind or solar power was the cheapest source of new electricity in 34 percent of U.S. counties, and costs have continued to decline since then.[20] This success is beginning to bear fruit: U.S. power sector emissions have declined 33 percent from 2005 levels, and wind and solar power are poised for rapid build-out in the 2020s.[21]

Figure 2: Cost reductions and capacity build-outs in wind energy and solar PV[22]



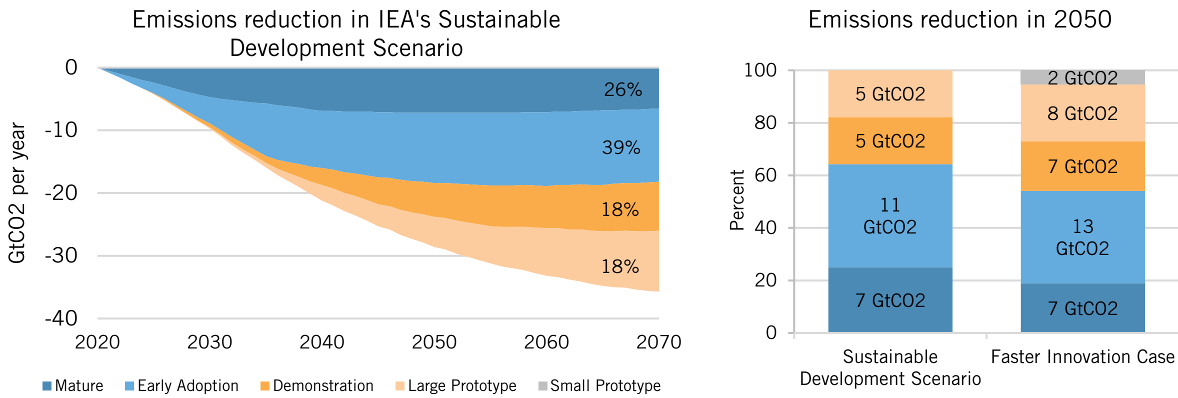
The challenge is to replicate the success of wind and solar power with other clean technologies and across all sources of emissions. In the power sector, new affordable, carbon-free firm generation that is available 24/7 and can be dispatched on-demand will be needed to achieve a carbon-free electricity system.[23] In the transportation sector, EVs are projected to reach cost parity with gas-powered cars in the 2023–2025 time range, but significant hurdles related to charging times, driving range, availability of charging infrastructure, and impacts to the grid must be addressed.[24] In buildings, high-efficiency heat pumps and low-global-warming-potential refrigerants can reduce emissions from heating and cooling, but costs must come down to enable wider deployment.

Innovation challenges are even more acute for harder-to-abate sectors.[25] Aviation, marine shipping, and long-distance trucking are more challenging to electrify than light-duty cars and trucks, and will likely require carbon-neutral fuels that are as energy dense as the petroleum-based fuels they would replace. Heavy industries such as steel, cement, and chemicals are especially challenging to decarbonize due to process emissions from chemical transformations and emissions from high-temperature heat. Many promising solutions are being developed but must be validated and demonstrated at commercial scale before they will make a dent in emissions.[26]

IEA's *Energy Technology Perspectives 2020* report finds that large shares of the global annual emissions reductions necessary to achieve net-zero emissions in the coming decades will likely come from technologies that are at the demonstration or prototype stage of development and are not yet commercially available today (figure 3). In IEA's Sustainable Development Scenario, which reaches global net-zero emissions in 2070, 36 percent of annual emissions reductions in 2070 will come from technologies in these stages. In the Faster Innovation Case, which achieves net-zero global emissions by 2050, nearly half of annual emissions reductions come from technologies in the demonstration, large prototype, or small prototype stage of development (figure 3).[27]

In the past, new energy technologies—even recent successful consumer products such as LEDs and batteries—have taken 20 to 70 years to go from the first prototype to 1 percent market share.[28] The world will not achieve its climate aspirations if innovation moves that slowly in the future. Assertive RD&D and market creation efforts are needed in the 2020s to develop, improve, and scale up nascent, low-carbon energy technologies so they are available as near-term decarbonization opportunities reach their limits.

Figure 3: Global energy sector CO_2 emissions reductions by current technology maturity category[29]

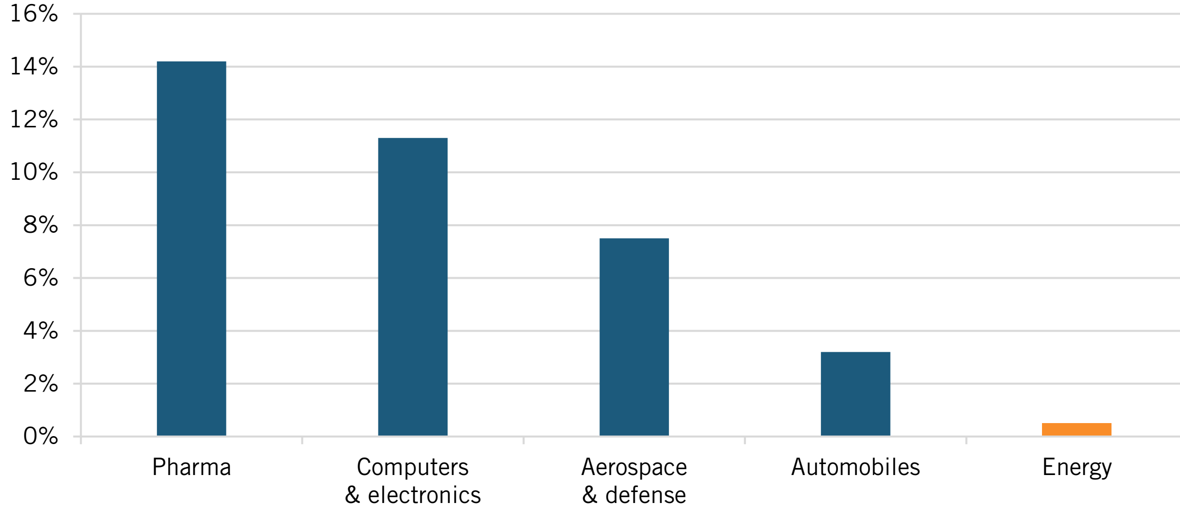


THE KEY ROLE OF THE FEDERAL GOVERNMENT IN THE U.S. ENERGY SYSTEM

Many technologies that now make major contributions to both the U.S. and global energy systems were created through federal investments and public-private cooperation.[30] Federally funded nuclear power RD&D, for instance, led to large-scale private investment in commercial power plants that now account for 20 percent of U.S. electricity generation and 54 percent of zero-carbon power generation.[31] Federal support for shale gas resource characterization and directional drilling—in tandem with industry-matched applied research and a federal production tax credit—led to the dramatic rise of shale gas production from less than 1 percent of domestic gas production in 2000 to nearly 80 percent in 2020 (see box 1).[32] Decades of investment and policy-driven market development have led to precipitous declines in the cost of new solar PV (89 percent cheaper since 2009) and new wind facilities (70 percent cheaper since 2009) (see box 2).[33]

But unlike software and biotech, which attract significant private investment, clean energy faces substantial scale-up and commercialization challenges.[34] Technology development lifecycles are long, and projects are often capital intensive and bear a significant amount of technical and financial risk.[35] For these reasons, the energy industry invests a very small share of its revenues, just 0.5 percent, in research and development (R&D).[36] 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 (figure 4).[37] 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.[38]

Figure 4: R&D spending as a percentage of revenue across major global industries, 2018



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 on performance and must therefore compete on price from the moment they enter the market.[39] Electric utilities are often legally mandated to keep prices low, and may be prohibited from investing in new technologies.[40]

Box 1: Federal Role in the Shale Gas Revolution

The shale gas revolution example illustrates the synergies of "technology push" and "market pull" policies working in concert to shepherd a new technology to market. Beginning in the late 1970s, the federal government funded fundamental research in directional drilling and shale resource characterization, countenanced and funded industry-wide collaboration in applied RD&D that might otherwise have drawn antitrust scrutiny, and subsidized industry-led demonstrations of the first horizontal wells in West Virginia and Texas. This technology push overlapped with a time-limited market-pull production tax credit for wells drilled between 1980 and 1992, with production eligible for the credit through 2002.[41] By 2002, when federal support tapered off, shale gas had grown to account for 2 percent of domestic gas production and was able to compete in the market on its own. Since then, hydraulic fracturing technologies, combined with vast domestic shale resources, have enabled shale gas to grow to 70 percent of domestic production.[42]

The federal government is uniquely suited to address these barriers by making high-risk, long-term investments the private sector is simply unwilling to fund. 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.

DOE's key role in bringing shale-gas technology to maturity is just one example in an impressive list of accomplishments. 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 (see box 3). 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. Basic research in subsurface fluid flow and high-strength materials by DOE in the early 1980s resulted in advancements in drilling that could soon enable expansion of enhanced geothermal energy to large parts of the country.[43] 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.

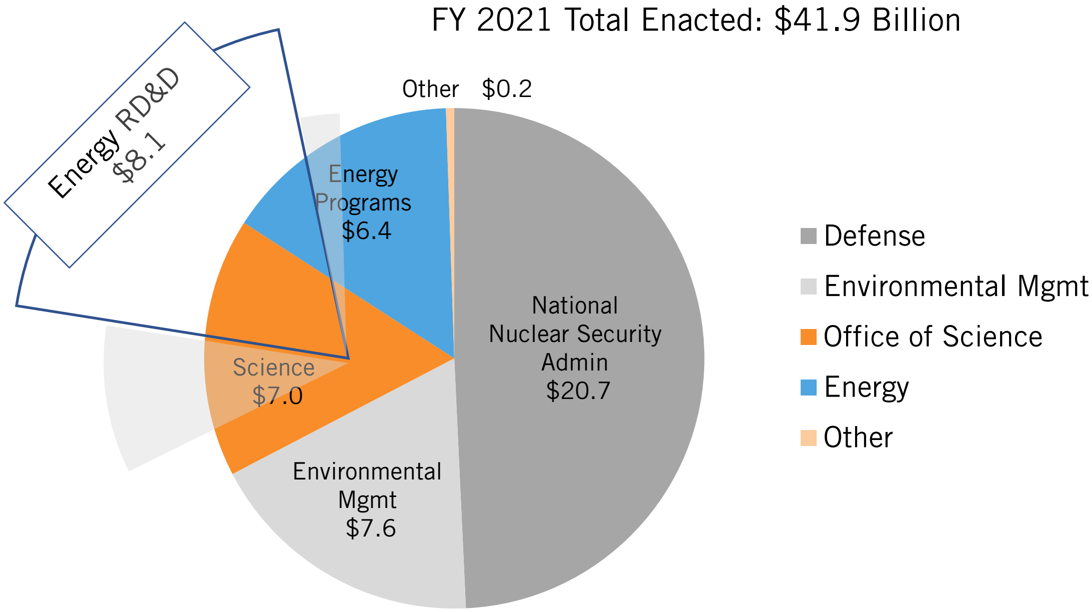
Box 2: DOE Loan Guarantees Launched Utility-Scale Solar PV

The evolution of solar PV technologies similarly exemplifies the role of smart public policy in accelerating innovation and the synergistic interactions between public and private investment. In the 1970s and 1980s, government and university R&D was responsible for most of the performance improvements and cost reductions in solar PV modules. During that time, the nascent solar industry was supported by the emergence in the public sector of niche applications—primarily for use in satellites—at NASA and the Defense Department that were relatively insensitive to cost. As the technology matured and the solar industry expanded, pull policies such as tax incentives, net-metering, feed-in tariffs, and state portfolio standards helped expand the market for solar and also incentivized greater private sector investment, which enabled the industry to take advantage of economies of scale. In 2011, the DOE Loan Programs Office provided loan guarantees to the first five utility-scale solar PV facilities larger than 100 megawatts (MW).[44] Thanks in large part to these policies working together in the United States and globally, the cost of solar PV panels has declined by 99 percent over the last four decades.[45]

THE DEPARTMENT OF ENERGY… AND LOTS OF OTHER STUFF

The name "Department of Energy" may leave the mistaken perception that DOE's primary function is overseeing and improving the nation's energy system. In reality, when other activities of DOE—defense, environmental cleanup, and non-energy-focused basic science—are taken into account, only a small portion of its budget supports energy innovation. Figure 5 shows DOE's budget by organization. The department's $8.1 billion energy RD&D portfolio includes portions of the Office of Science and the energy programs.

Figure 5: DOE budget by major function, FY 2021 (in billions)



DOE was assembled in 1977 from previously scattered federal agencies, the largest of which was the Atomic Energy Commission, which had managed the military's nuclear weapons program since just after World War II. DOE's National Nuclear Security Administration (NNSA) carries out such defense responsibilities today. NNSA and other defense programs housed within DOE comprise more than 49 percent of the agency's nearly $42 billion budget. In addition, DOE's Office of Environmental Management (EM) is tasked with cleaning up the massive pollution left behind by the weapons program. EM's budget is more than $7.5 billion, comprising 18 percent of DOE's budget. Together, these two slices make up more than two-thirds of the department's budget.

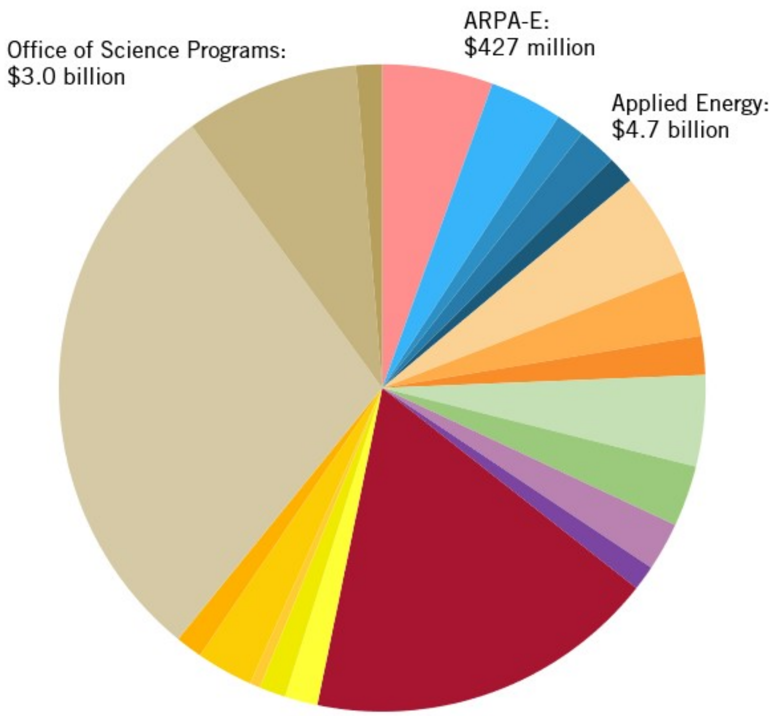
DOE's $7 billion Office of Science (SC) is one of the government's largest funders of basic science research, providing critical research infrastructure through its support for 10 of DOE's 17 national laboratories. SC research is spread across six program areas: Advanced Scientific Computing Research, Basic Energy Sciences (BES), Biological and Environmental Research (BER), Fusion Energy Sciences (FES), High Energy Physics, and Nuclear Physics. While SC is an important component of the nation's discovery science ecosystem, less than half of its budget is specifically devoted to advancing energy research. (ITIF includes only BES, FES, and the portion of BER that supports bioenergy research centers in its definition of energy-related research.)

DOE's energy programs include both RD&D and non-RD&D functions. Most of the energy RD&D budget is distributed across DOE's applied energy offices: Energy Efficiency and Renewable Energy, which houses programs in renewable energy, sustainable transportation, and energy efficiency; Electricity, which supports grid modernization; Cybersecurity, Energy Security, and Emergency Response (CESER); Fossil Energy and Carbon Management; and Nuclear Energy. The Advanced Research Projects Agency for Energy (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.

Portions of DOE's energy programs support other critical functions. The Energy Information Administration provides data and analysis to identify energy demand and supply and model the U.S. energy system to project future trends. The Weatherization Assistance Program supports deployment of energy-conserving technologies for low- and moderate-income households. The Office of Indian Energy supports financing of energy infrastructure projects on tribal lands (analogous to the Rural Utility Service at the U.S. Department of Agriculture). DOE's State Energy Program provides technical assistance and support to states, primarily to support state-level energy offices. The Strategic Petroleum Reserve and other fuel reserves maintained by DOE provide critical insurance against potential interruptions in U.S. fuel supplies. These additional functions, though important, are not part of the energy innovation budget.

DOE's entire energy RD&D portfolio—including the applied energy programs, portions of the DOE SC, and ARPA-E—totals $8.1 billion, or about 19 percent of DOE's budget (figure 5). The portfolio spans 21 science and technology program areas across 7 technology categories, shown in figure 6: renewable energy; transportation; energy efficiency; energy transmission, storage, and distribution (TS&D); nuclear energy; fossil energy and carbon management; and basic energy-related research.

Figure 6: DOE's energy RD&D funding by program area, FY 2021



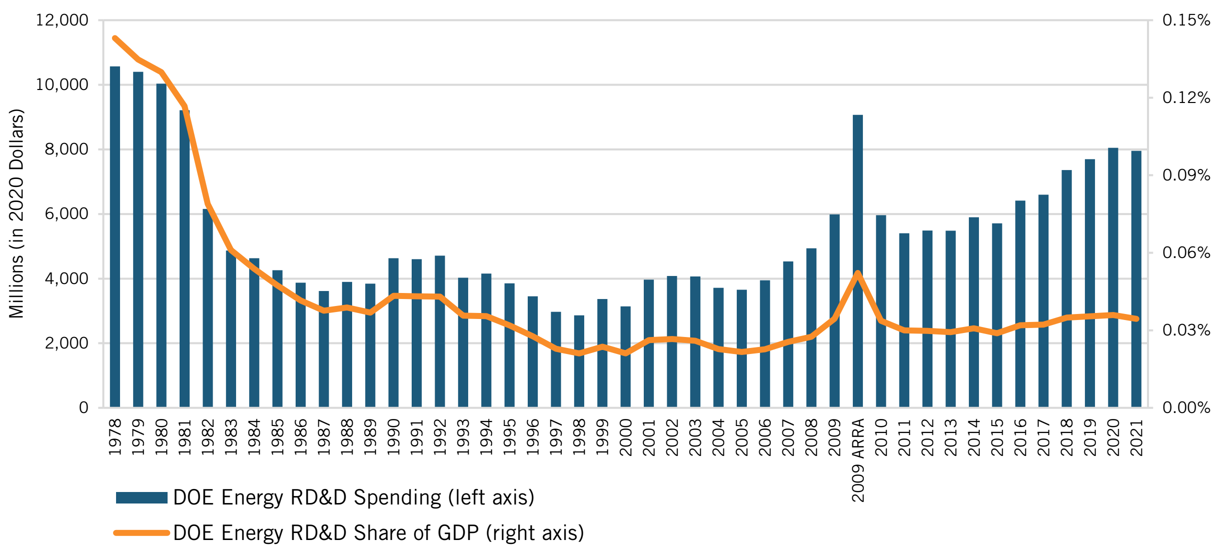
ARPA-E	ARPA-E
Renewable Energy	Solar Wind Water Geothermal
Sustainable Transportation	Vehicles Bioenergy H_2 & Fuel
Energy Efficiency	Manufacturing Buildings
Energy TS&D	Grid Mod Cyber
Nuclear	Nuclear
Fossil Energy & Carbon Mgmt	CO_2 Capture CO_2 Storage CO_2 Removal Adv Fossil Oil & Gas
Office of Science	Basic Energy Fusion Bioenergy

The federal government has not always been so stingy. At the time of DOE's creation in the late 1970s, energy demand was increasing rapidly, energy prices were high and rising, and the Arab oil embargo and formation of OPEC (Organization of the Petroleum Exporting Countries) sparked fears of rising energy insecurity and dependence. 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.[46]

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.[47] 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.[48] 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 7).

Figure 7: U.S. DOE Energy RD&D spending, FY 1978 through FY 2021[49]



DOE RD&D: GENERATING HUGE RETURNS ON A MODEST BUDGET

Despite a relatively small investment, federal energy RD&D has delivered big returns for the American public. DOE's investments have led to commercialization of new products, lower costs and speedier deployment of clean technologies, energy savings for consumers and businesses, less pollution from dirty energy, and greenhouse gas emissions reductions. DOE research has won more than a third of the top 100 R&D awards given out annually by *R&D World* magazine for each of the last four years.[50] 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 (see box 4 for DOE's buildings and appliances return on investment).[51]

DOE research has also helped reduce the environmental impacts of fossil fuel consumption and made the United States a world leader in pollution control technologies. 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.[52] 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) (see box 5).[53] 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.[54]

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.

Box 3: Launching the Pollution Control Industry

Federal investments in pollution control technologies provide an example of the multiple benefits of energy RD&D. Prior to DOE's coal RD&D programs, flue gas desulfurization (FGD) systems (aka "scrubbers") were costly to build and maintain, incurred substantial energy costs to run, and produced a sludge waste requiring considerable land use for proper disposal. Advancements in pollution control helped drive capital and operating costs down by nearly 50 percent, kept energy costs low, and turned the waste from FGD scrubbers into valuable byproducts such as wallboard-grade gypsum.[55] DOE investments in FGD scrubbers resulted in over $50 billion in savings from lower FGD costs and public health benefits, and also helped turn America into a global leader in environmental technologies.[56] Environmental technologies and services contribute to a trade surplus, yielding net exports of nearly $27 billion annually.[57]

Energy and Climate Benefits of DOE Programs

For each of its applied energy programs, DOE sets technology cost/performance targets based on the RD&D activities possible at a given budget level. As part of its goal-setting process, DOE and laboratory experts assess the ability of its program activities to improve a technology's characteristics (e.g., capital cost) and move it closer to commercialization. In conducting this analysis, DOE assumes that funding levels will remain constant over time.

Perhaps the best-known target was set by DOE's SunShot Initiative. Launched in 2011 to make solar energy cost competitive with conventional generation, the initiative aimed to reduce the cost of utility-scale solar PV by 75 percent by 2020, to a nationwide average of 6 cents per kilowatt-hour ($0.06/kWh). That would be within the range of the levelized cost of electricity from a natural gas combined cycle power plant, which was $0.044–0.073/kWh in the United States in 2020.[58] The cost target was achieved three years early, in 2017, prompting DOE to launch new SunShot 2030 goals: $0.03/kWh for utility-scale PV, $0.04/kWh for commercial-scale PV, and $0.05/kWh for residential PV.[59] Achieving these price reductions could result in solar energy meeting 14 percent of U.S. electricity needs by 2030 (up from 2 percent in 2020), support 290,000 new solar jobs, and translate into $30 billion in annual energy cost savings by 2030.[60]

Box 4: Buildings and Appliances

Investments in DOE's Building Technologies Office (BTO) between 2010 and 2015 culminated in the successful commercialization of 27 products across a range of energy-related technologies, including energy-efficient water heaters, solid-state lighting, and energy-saving windows. For example, the advanced dual evaporator technology for refrigerators—which performs up to 50 percent better than conventional single-cycle refrigeration systems—was developed with assistance from BTO and successfully commercialized by Whirlpool Corporation in 2013.[61] A retrospective assessment of BTO investments between 1976 and 2015 across three technology areas—HVAC, water heating, and appliances—found that BTO investments yielded between $6 billion and $22 billion in economic benefits, with a benefit-to-cost ratio of between 20:1 and 66:1.[62] BTO's current goal is to reduce the average energy use per square foot of all U.S. buildings by 30 percent by 2030, which would decrease total energy use by 5 quadrillion BTUs and save consumers over $100 billion in energy costs annually.[63]

Recent rapid cost declines have enabled even greater ambition. In March 2021, DOE announced that it is moving up its SunShot goal by five years, targeting $0.03/kWh by 2025. And it announced a new target of $0.02/kWh by 2030.[64]

Other notable DOE technology targets include:[65]

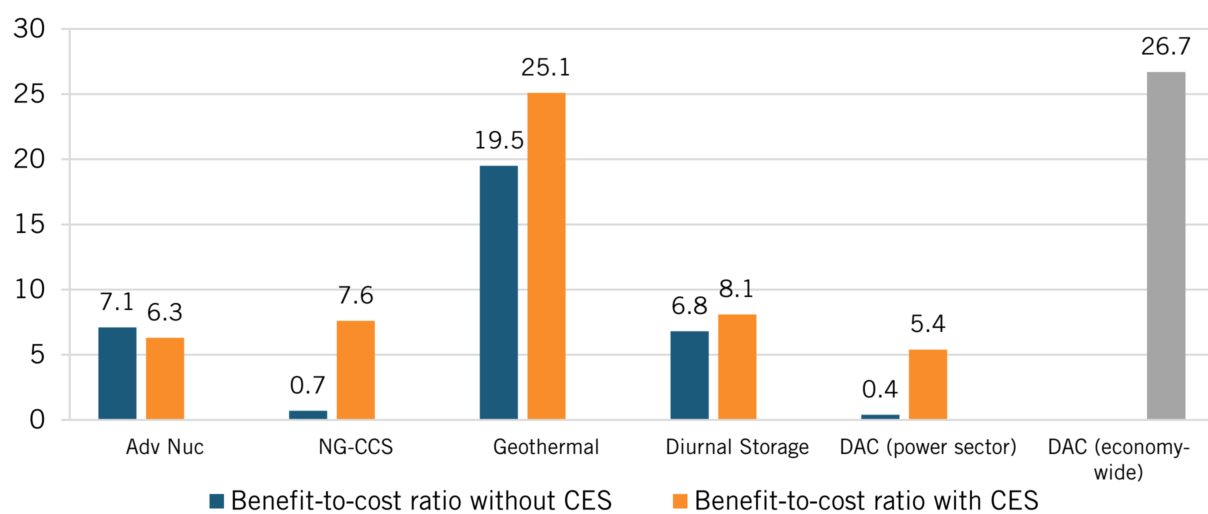
- Reducing average building energy use per square foot by 30 percent from 2010 levels by 2030, saving consumers up to $100 billion annually in energy costs, and cutting carbon emissions by 450 million metric tons;[66]
- Reducing the cost of batteries for EVs to $100/kWh, increasing their range to 300 miles, and decreasing charging time to 15 minutes by 2028, bringing the total cost of ownership of EVs in line with that of conventional cars and trucks;[67]
- Reducing the cost of hydrogen production (to $2 per kilogram) and hydrogen storage (to $1 per kilogram), which could open up new applications for clean hydrogen in key transportation and industrial sectors;[68]
- Reducing the cost of carbon capture to under $30 per metric ton, which could result in up to 30 gigawatts of carbon capture technologies and more than 150 million metric tons of CO_2 sequestered by 2030;[69] and
- Reducing fugitive emissions from natural gas systems by 40–45 percent, which would improve public safety, reduce greenhouse gas emissions, and ensure that more natural gas makes its way from the producer to the end customer.[70]

If DOE meets its targets, the nation would gain significant benefits, including lower consumer energy bills and better health and environmental outcomes. A 2017 DOE analysis concluded that if its current RD&D programs were to meet their targets for reducing the costs and improving the performance of clean energy technologies, U.S. carbon emissions could fall 23 percent by 2040 and lower residential energy bills by 25 percent.[71] And if DOE doubled its RD&D budget, better technologies could reduce U.S. emissions by an additional 15 percent. These projections may be conservative, as between 2012 and 2017, DOE met or exceeded 75 out of 76 technology targets. Clearly, RD&D is an important part of the decarbonization tool kit.[72]

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

DOE is now preparing to launch new programs across a range of advanced energy technologies in response to the Energy Act of 2020. In April 2021, Resources for the Future (RFF) released a study of the potential impact of additional funding across five of the technologies: advanced nuclear, natural gas with carbon capture and sequestration (NG-CCS), advanced geothermal, diurnal energy storage, and direct air capture of CO_2 (DAC). The study projects future cost reductions resulting from the additional RD&D funding and estimates the benefits of these cost reduction under a scenario with and without a national clean electricity standard (CES). Benefits include electricity bill savings, reduced health damages, and reduced climate damages. The study finds average power sector benefits are likely to exceed costs by a factor of 7 without a CES, and by a factor of more than 10 with a CES. Average annual electricity bill savings for each household are about $14 without a CES and $56 with a CES.[73]

Figure 8: Estimated benefit-to-cost ratios from 10 years of higher RD&D funding across 5 technologies[74]



2021: A CRITICAL OPPORTUNITY FOR ENERGY INNOVATION

2021 presents a critical opportunity to rapidly scale up U.S. investment in energy innovation. In a polarized political system, energy innovation has long enjoyed bipartisan support. Large majorities of voters across the political spectrum support more funding for research into clean energy. A December 2020 poll found that 82 percent of registered voters support funding more research into clean energy sources such as solar and wind power.[75] And lawmakers from diverse backgrounds have embraced energy innovation as a strategy to combat climate change and promote U.S. competitiveness. From 2011 to 2020, Congress increased federal funding for energy RD&D in every single year except 2015. And support is growing. In Congress, Democrats and Republicans have joined forces to advance legislation around energy storage, advanced renewables, carbon capture, and nuclear.

So far, these efforts have contributed modest, though important, expansions to the federal energy innovation system. Over the past four years, Congress has provided a 40 percent increase in the energy RD&D programs at DOE, reversing decades of neglect and declining investments. However, DOE's energy RD&D budget for FY 2021 remains more than 20 percent below what it was when the department was established in 1978. And current funding levels are far below what is needed to match the urgency of climate change and advance U.S. competitiveness in clean energy.

But the 2021 budget cycle may be different. In December 2020, Congress came together to pass the Energy Act of 2020, a sweeping overhaul of DOE's programs, and the first major reauthorization in more than a decade. The Energy Act creates new programs to address technology gaps, expands programs to scale up and commercialize technologies developed in the labs, and authorizes significant boosts in funding for some key technologies. More than 100 members of Congress contributed to portions of the bill. This monumental achievement signifies greater attention and focus on the need for energy innovation, and could be a launchpad for more action in 2021.

Additionally, the number of voices calling for substantially greater investment—not just incremental increases—is growing, as lawmakers and prominent voices on both sides of the aisle have called for doubling, tripling, or even quintupling federal innovation. The debate is no longer over whether to scale up energy innovation—only how much and what to invest in.

Energy Act of 2020: A Significant Step Forward

The Energy Act of 2020 delivers a monumental overhaul of DOE programs—the first significant reauthorization since the Energy Independence and Security Act of 2007, and one of the biggest, wholly bipartisan advancements in clean energy innovation policy in over a decade.[76]

The road to enactment began in the Senate Energy and Natural Resources committee in 2015, when then-Chairman Murkowski (R-AK) and Ranking Member Cantwell (D-WA) launched a bipartisan effort to develop a comprehensive update to national energy policy. Their effort resulted in the Energy Policy Modernization Act of 2015 (EPMA). EPMA easily passed the Senate and was successfully conferenced with the House, but the House ended the 114th Congress early without a chance to vote on the final conference report. In 2019, the process began again, with Chairman Murkowski and (the new) Ranking Member Manchin (D-WV) bringing the bipartisan American Energy Innovation Act to the floor of the Senate in February 2020. The House Science, Space, and Technology Committee—which has jurisdiction over DOE's RD&D programs—began a parallel process under Chair Johnson (D-TX) and Ranking Member Lucas (R-OK), producing a number of bipartisan bills spanning a range of clean technologies.[77]

This activity culminated in the 530-page Energy Act of 2020, which includes the areas of greatest agreement between the House and Senate energy packages. It was included in the omnibus appropriations act passed by Congress in December 2020.

The Energy Act modernizes and refocuses DOE's RD&D programs to address critical energy innovation challenges. Technology has evolved rapidly since 2007: New challenges have emerged, and priorities have evolved, highlighting the need to revisit DOE's authorizations. The Energy Act:[78]

- Revises and updates program authorizations to account for technological advances over the last decade and to address current and emerging challenges;
- Creates new programs in clean manufacturing and carbon removal—sectors that have historically been underrepresented in DOE's portfolio; and
- Provides the first significant new investment in large-scale demonstration projects—which are essential for scaling up and validating emerging technologies—in more than a decade.

Some gaps remain. Certain technologies received comparatively less attention, and some program reauthorizations did not make it into the final bill. A key challenge facing the current legislature is providing sufficient funding to match innovation challenges, and addressing remaining gaps. But success builds its own momentum. The Energy Act of 2020 showed that Congress can come together in a bipartisan manner to address national challenges. This success makes it more likely that Congress will take the next step.

Box 5: Carbon Capture on the Cusp?

CCS may be on the cusp of significant new build-outs and cost reductions, thanks in part to DOE's work in developing and demonstrating carbon capture technologies. DOE's Industrial Carbon Capture and Storage 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.[79] The Petra Nova coal power plant began capturing its carbon emissions in 2017 at a cost of about $60 per ton. (Although the plant closed due to declining revenues as a result of the COVID-19 pandemic, it was successful in facilitating learning that is projected to lead to 30 percent cost reduction for similar second-of-a-kind projects.)[80] 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.[81] And in February 2018, Congress expanded and extended the 45Q tax credit to incentivize greater utilization and storage of captured CO_2.[82]

The Energy Act of 2020 provides a significant expansion of DOE's programs that could further accelerate carbon capture. It expands R&D activities beyond just power plants to include manufacturing facilities such as cement and steel plants. It also creates a new program to conduct large-scale pilot projects at a scale "beyond laboratory development and bench scale testing, but not yet advanced to the point of being tested under real operational conditions at commercial scale."[83] And it directs DOE to begin six commercial demonstrations of carbon capture by 2025—two each at coal power plants, natural gas power plants, and industrial facilities.

Taking the Next Step: Time for a Moon Shot in Clean Energy

The successful passage of the Energy Act of 2020 positions Congress to aim for new levels of ambition and launch a moon shot for clean energy. Public support is coalescing around the need for massive scale-up of federal innovation programs. And a growing chorus of science and technology policy experts is calling for substantial scale-ups and new investments in the national innovation ecosystem.

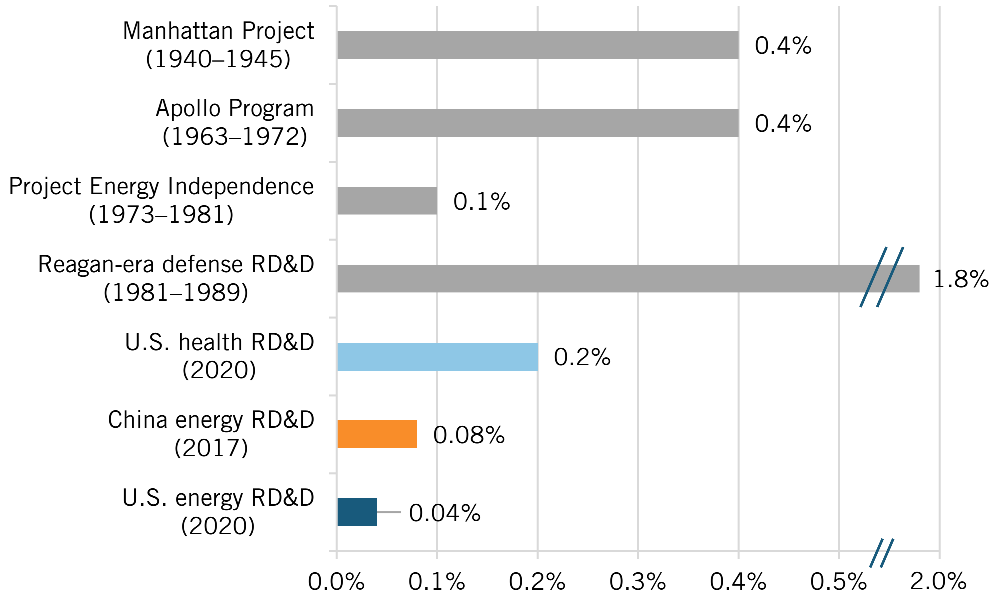
Last year, ITIF partnered with CGEP to produce *Energizing America: A Roadmap to Launch a National Energy Innovation Mission*. The volume calls on Congress and the president to triple funding for energy RD&D over five years in order to harness the nation's innovative capabilities and speed the progress of clean energy technologies. *Energizing America* provides a strategic framework for building a growing RD&D portfolio, with detailed funding proposals across the full spectrum of critical energy technologies.[84]

Other prominent figures have recommended similarly ambitious increases. A pair of recent studies from the National Academies of Sciences, Engineering, and Medicine (NASEM)—*Accelerating Decarbonization of the U.S. Energy System* and *The Future of Electric Power in the U.S.*—call on policymakers to triple energy RD&D.[85] The tripling target has also been recommended by the American Energy Innovation Council (AEIC), the Center for Climate and Energy Solutions (C2ES), and the President's Council of Advisors in Science and Technology.[86] Breakthrough Energy has called for a fivefold increase in funding to $35 billion by 2030, which would bring energy RD&D to roughly 0.1 percent of GDP, in line with historical levels of energy investment, and roughly in line with health spending ($38 billion in 2020).[87]

ITIF joined the Clean Air Task Force, Edison Electric Institute, and other energy utilities and leading energy and climate think tanks to launch the Carbon-Free Technology Initiative, which provides an innovation agenda to develop and commercialize the firm, carbon-free, dispatchable technologies necessary to completely decarbonize the electric power system. The initiative develops detailed policy proposals—building on the policy developments from the Energy Act of 2020—across key technology areas, and recommends tripling investment in power-sector RD&D at DOE.[88] And in May 2021, more than 100 energy and environmental organizations, industry groups, and research institutions jointly signed a letter calling on congressional leadership to provide an FY22 appropriations allocation that enables a multi-billion-dollar increase in the research, development, demonstration, and commercial deployment activities at DOE.[89]

These targets are both ambitious and measured. Other national innovation missions in space, health, and defense show that the United States can marshal its innovative capacity on a much larger scale than it currently does for energy (figure 9). Federal investment in RD&D has accelerated the development of life-saving drugs, modernized the military's arsenal, and put a man on the moon. By comparison, the federal government has neglected energy innovation.

Figure 9: Federal RD&D funding as a percentage of GDP for selected national innovation missions[90]



The American Jobs Plan and President Biden's Budget Request for FY 2022

The American Jobs Plan

The American Jobs Plan proposes dramatically increased federal investments—around $2 trillion over the next decade—in the infrastructure and innovation underpinnings of America's economy, including investments in RD&D and manufacturing.[91] The plan would reverse a decades-long decline in innovation funding, with Federal RD&D investment across all sectors falling to pre-Sputnik levels, and the United States slipping to 10th place among Organization for Economic Cooperation and Development (OECD) countries in national RD&D intensity.[92]

The plan includes proposals to advance clean energy innovation, including both RD&D and early deployment and market expansion policies. Key climate and energy innovation provisions include:[93]

- $40 billion investment to upgrade the research infrastructure in laboratories across the country, including DOE's 17 national labs;
- $35 billion investment in climate science, innovation, and R&D, with a $5 billion increase in funding for climate-focused research and $15 billion in demonstration projects in utility-scale energy storage, CCS, hydrogen, advanced nuclear, rare earth separations, floating offshore wind, biofuels and bioproducts, quantum computing, and EVs;
- $20 billion in regional innovation hubs to fuel technology development, link urban and rural economies, and create new businesses in regions beyond the current high-growth centers;
- $10 billion R&D investment at historically black colleges and universities (HBCUs) and other minority-serving institutions (MSIs), and $15 billion to create up to 200 centers of excellence that serve as research incubators at HBCUs and other MSIs;

- $10 billion investment in a new green jobs training program—a Civilian Climate Corps—to support the skilled workforce needed to produce advanced technology goods;
- 10 pioneer projects that demonstrate carbon capture retrofits for large steel, cement, and chemical production facilities;
- 15 clean hydrogen demonstration projects; and
- A new Advanced Research Projects Agency-Climate (ARPA-C) to develop new methods for reducing emissions and building climate resilience.

In addition, the proposal includes investments in EV chargers, transmission incentives, government procurement, and other policies to expand markets for clean energy. The plan is currently being developed into congressional legislation, with more details about how the proposal would impact DOE's energy RD&D budget likely to emerge in the late-Spring to early-Summer 2021.

The Biden Administration's Budget Request for FY 2022

In April 2021, the Office of Management and Budget released the outline of President Biden's budget request for FY 2022. The request calls for quadrupling government-wide investment in clean energy innovation over the next four years, providing a much-needed boost in federal innovation programs.[94] Highlights include:

- $46.1 billion for DOE, a $4.3 billion (10 percent) increase over FY 2021;
- $10 billion for government-wide clean energy innovation programs, of which $8 billion would go to DOE programs;
- $7.4 billion for DOE SC, which conducts basic energy science research, as well as discovery science and advanced computing research;
- $1 billion for a new ARPA-C and the existing ARPA-E, of which $700 million is funded through DOE;
- Refocusing the Office of Fossil Energy and Carbon Management on carbon reduction and mitigation, and expanding to include industrial carbon capture, hydrogen, and direct air capture;
- $1.9 billion for a new Clean Energy Projects and Workforce Initiative, with investments to support infrastructure and grants to state, local, and tribal governments to support clean energy deployment in marginalized communities; and
- Support for economic revitalization for coal and power plant communities.

The initial budget guidance is short on details, and will be supplemented by the full budget justification documents in the coming months.

Table 1: DOE budget by program area, FY 2019 enacted through FY 2022 request, in millions of dollars.

	FY 2019 Enacted	FY 2020 Enacted	FY 2021 Enacted	FY 2022 WH Request
DOE Total Budget	35,685	38,657	41,927	46,100
Defense	16,089	17,611	20,652	
Environmental Management	7,175	7,425	7,586	
Basic Science Research	3,755	4,016	4,009	
DOE Energy RD&D Programs*	7,917	8,788	8,931	
ARPA-E	366	425	427	700**
Energy Efficiency & Renewable Energy	2,379	2,790	2,862	
Sustainable Transportation				
Vehicle Technologies	344	396	400	
Bioenergy Technologies	226	260	255	
Hydrogen & Fuel Cell Tech	120	150	150	
Renewable Energy				
Solar Energy	247	280	280	
Wind Energy	92	104	110	
Water Power	105	148	150	
Geothermal Technology	84	110	106	
Energy Efficiency				
Advanced Manufacturing	320	395	396	
Building Technologies	226	285	290	
Fossil Energy R&D	740	750	750	
CCUS and Advanced Power	486	491	447	
Natural Gas Technologies	51	51	57	
Unconventional Oil Tech	46	46	46	
NETL Research	51	50	83	
Nuclear Energy	1,326	1,493	1,508	
Reactor Concepts RD&D	324	267	208	
Nuclear Energy Enabling Tech	153	113	123	
Fuel Cycle R&D	264	305	309	
Advanced Reactor Demos	--	230	250	
Versatile Test Reactor***	--	--	45	
Electricity Delivery	156	190	212	
Cybersecurity (CESER)	120	156	156	
Science	6,585	7,000	7,026	7,400
Basic Energy Sciences	2,166	2,213	2,245	
Fusion Energy Sciences	564	671	672	
BER Bioenergy Research	100	100	100	

* Energy programs include some non-RD&D functions, so RD&D funding is less than the sum of office budgets.

** The FY22 budget requests $1 billion for ARPA-E, with $700 million through DOE and $300 million through other agencies.

*** The Versatile Test Reactor was previously funded in FY 2018 and FY 2019 out of the Reactor Concepts RD&D subprogram.

WHAT HAPPENS NEXT

The full budget request and supporting DOE Congressional Budget Justification documents are expected to be released in late Spring 2021. These documents will provide granular funding levels and more details about what the president is requesting and why.

The House and Senate Appropriations committees have already begun holding hearings to solicit testimony and input on their FY 2022 bills. The House Energy & Water Development subcommittee held its first hearing in February on "Strategies for Energy and Climate Innovation," which focused on DOE's clean energy innovation programs.[95] The committee has also held hearings on investment and innovation in water resources infrastructure and domestic clean manufacturing.[96] It has scheduled a hearing on the FY 2022 budget request for DOE on May 6.[97]

The next step is for the House and Senate to agree on an overall top-level discretionary budget for FY 2022. The Appropriations committees must then 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. 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.[98]

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 authorizing committees are continuing the process of modernizing and updating DOE's programs, picking up where the Energy Act of 2020 left off. The House Committee On Science held hearings on building technologies, which were left out of the Energy Act, as well as sustainable aviation, a hard-to-abate source of emissions.[99] House Science has scheduled a hearing on "Climate and Energy Science Research at DOE" on May 4.[100] The U.S. Senate Committee on Energy and Natural Resources has also held hearings on carbon utilization technologies, transportation technologies, and nuclear energy, as well as on the larger role of DOE in energy innovation.[101]

While these hearings are unlikely to impact the budget for FY 2022, they do indicate continuing engagement on emerging innovation challenges and attention to gaps that were not addressed in the Energy Act. These hearings could lead to new legislation to reauthorize and update existing DOE programs, or create new ones.

CONCLUSION

The United States has a proud history of rising to global challenges by unleashing its potential to innovate. If policymakers decisively invest in the clean energy technologies of the future and sustain that investment, history can repeat itself. Nearing the end of the global coronavirus crisis, the United States should lead the response to climate change and prosper as the world transitions to clean energy. As Congress considers its FY 2022 appropriations, it has a tremendous opportunity to accelerate domestic clean energy industries and shape the U.S. response to climate change. It should build on the foundations paved by the Energy Act of 2020, and continue to elevate energy innovation as a national priority.

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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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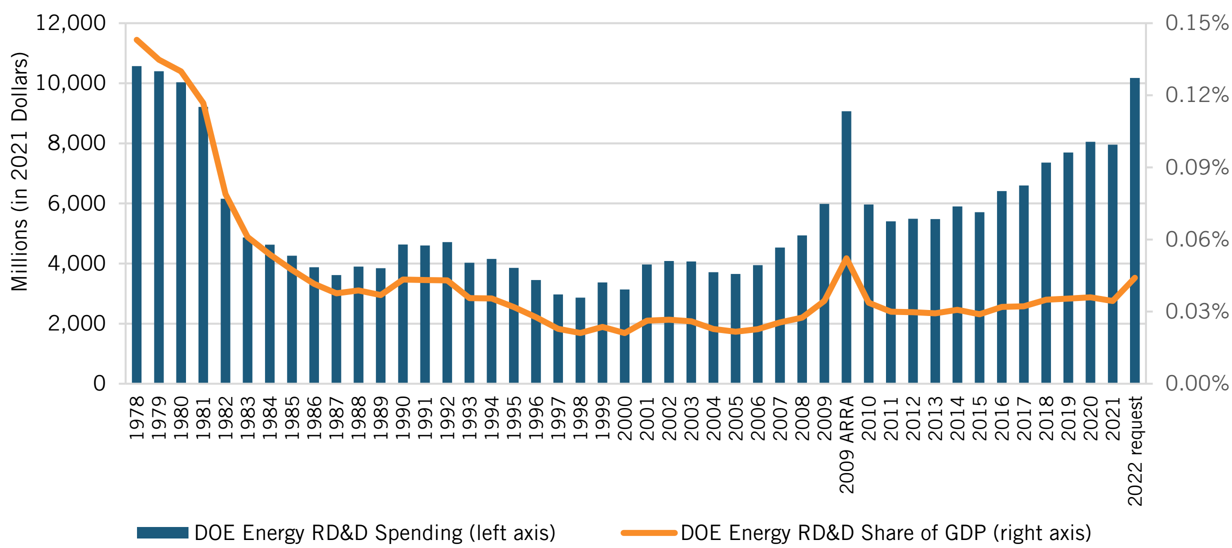
ITIF | INFORMATION TECHNOLOGY & INNOVATION FOUNDATION

Energizing Innovation: June 2021 Update

BY LINH NGUYEN AND DAVID M. HART | JUNE 2021

In June 2021, the Office of Management and Budget released the President Biden's full FY 2022 budget request, building on its April outline. The request calls for quadrupling government-wide investment in clean energy innovation over the next four years, which would provide a much-needed boost. This document updates key data in our April 2021 report and provides some highlights from the president's request.

Figure 1: U.S. DOE Energy RD&D spending, FY 1978 through FY 2022 Request[1]



The Biden Administration's Budget Request for FY 2022

Highlights include:

- A substantial increase in the Department of Energy's (DOE) energy RD&D funding, surpassing the 2009 total (which includes one-time spending from the American Recovery and Reinvestment Act) and almost reaching 1978 levels in real terms (see figure 7);
- $46.1 billion for DOE, a $4.3 billion (10 percent) increase over FY 2021; [2]
- $12 billion for DOE energy RD&D programs (see table 1); [3]
- $1 billion for a new ARPA-C and the existing ARPA-E, of which $700 million is funded through DOE;[4]
- Refocusing the Office of Fossil Energy and Carbon Management on carbon reduction and mitigation, and expanding to include industrial carbon capture, hydrogen, and direct air capture;[5]

- $400 million for a new Office of Clean Energy Demonstration. OCED will use the funding to begin operations and issue an initial competitive solicitation on commercial-scale energy storage demonstrations;[6]
- $2.3 billion for basic energy sciences RD&D activities, a 2.4 percent increase from FY 2021 enacted levels; [7]
- $63 million for a new Carbon Dioxide Removal subprogram, within the Office of Fossil Energy and Carbon Management, that focuses on direct air capture, bioenergy with carbon capture and storage, and other mineralization concepts;[8]
- $550.5 million for the Advanced Manufacturing Office (AMO), a 39 percent boost from FY 2021 enacted levels. AMO subprograms would be completely restructured to address industrial decarbonization and manufacturing innovation;[9]
- $595 million for the Vehicle Technologies Office, including a 50 percent increase in the Materials Technology R&D subprogram and a 39 percent increase in the Battery and Electrification Technologies subprogram;[10]
- $197.5 million for the Hydrogen & Fuel Cell Technologies Office, a 32 percent boost from FY 2021 enacted levels;[11] and
- $204.87 million for the Wind Energy Technologies Office, including a 59 percent increase for offshore wind and 78 percent increase for distributed wind.[12]

Table 1: DOE budget by program area, FY 2019 enacted through FY 2022 request, in millions of dollars

	FY 2019 Enacted	FY 2020 Enacted	FY 2021 Enacted	FY 2022 WH Request
DOE Total Budget	35,685	38,657	41,927	46,192
Defense	16,089	17,611	20,652	20,913
Environmental Management	7,175	7,425	7,586	8,012
Basic Science Research	3,755	4,016	4,009	4,465
DOE Energy RD&D Programs*	7,917	8,788	8,931	11,967
ARPA-E**	366	425	427	700
Energy Efficiency & Renewable Energy	2,379	2,790	2,862	3,924
Sustainable Transportation				
Vehicle Technologies	344	396	400	595
Bioenergy Technologies	226	260	255	340
Hydrogen & Fuel Cell Tech	120	150	150	198
Renewable Energy				
Solar Energy	247	280	280	387
Wind Energy	92	104	110	205
Water Power	105	148	150	197
Geothermal Technology	84	110	106	164
Energy Efficiency				
Advanced Manufacturing	320	395	396	551
Building Technologies	226	285	290	382
Fossil Energy R&D	740	750	750	890
CCUS and Advanced Power	486	491	447	532

	FY 2019 Enacted	FY 2020 Enacted	FY 2021 Enacted	FY 2022 WH Request
Natural Gas Technologies	51	51	57	130
Unconventional Oil Tech	46	46	46	-
NETL Research	51	50	83	83
Nuclear Energy	1,326	1,493	1,508	1,851
Reactor Concepts RD&D	324	267	208	240
Nuclear Energy Enabling Tech	153	113	123	124
Fuel Cycle R&D	264	305	309	369
Advanced Reactor Demos	--	230	250	370
Versatile Test Reactor***	--	--	45	145
Electricity Delivery	156	190	212	327
Cybersecurity (CESER)	120	156	156	201
Science	6,585	7,000	7,026	7,440
Basic Energy Sciences	2,166	2,213	2,245	2,300
Fusion Energy Sciences	564	671	672	675
BER Bioenergy Research	100	100	100	-
Office of Clean Energy Demonstration	--	--	--	400

* Energy programs include some non-RD&D functions, so RD&D funding is less than the sum of office budgets.
** The FY22 budget requests $1 billion for ARPA-E, with $700 million through DOE and $300 million through other agencies. Of the $700 million, $200 million will go to a new ARPA-C program.
*** The Versatile Test Reactor was previously funded in FY 2018 and FY 2019 out of the Reactor Concepts RD&D subprogram.

ENDNOTES

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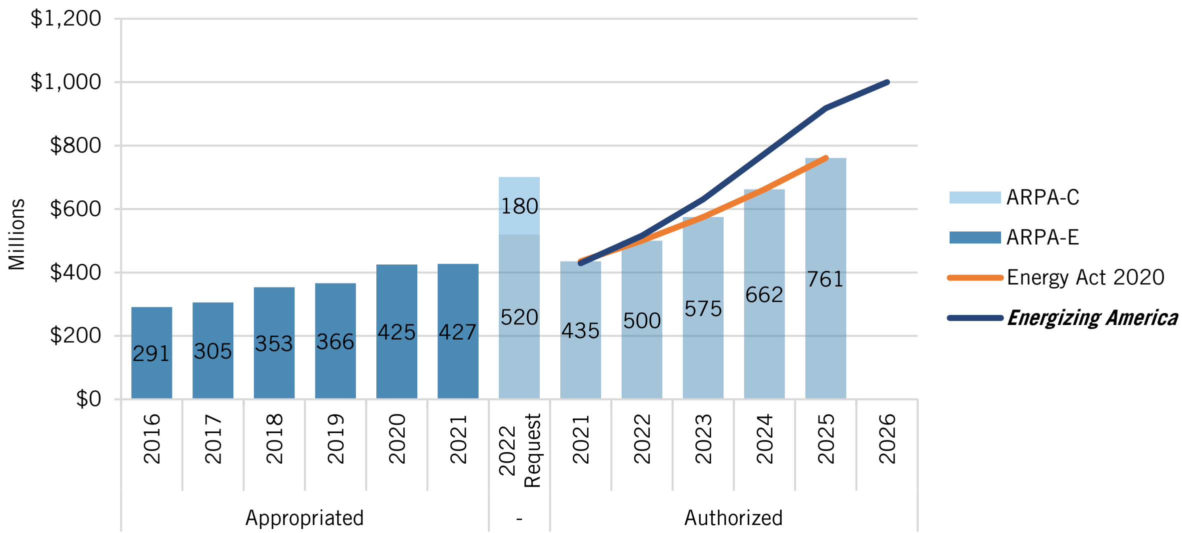
Federal Energy RD&D: ARPA-E

COLIN CUNLIFF AND LINH NGUYEN | JUNE 2021

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 crosscutting, real-world problems in transportation, electricity, building, and other sectors.

Figure 1: *Energizing America* recommends ramping funding to $1 billion in FY 2026. [1]



What's at Stake

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, development, and demonstration (RD&D) programs, ARPA-E was designed to focus more on the potential impact of the research that it funds and to fill "white spaces" unexplored by other federal energy RD&D programs. 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 2021, ARPA-E had provided $2.6 billion in RD&D funding to over 1,000 projects; 177 ARPA-E projects had attracted more than $4.9 billion in private-sector follow-on funding; 88 ARPA-E project teams had formed new companies to advance their technologies; and 237 ARPA-E projects had partnered with other government agencies for further development. Moreover, ARPA-E projects have generated 4,614 peer-reviewed journal articles, along with 716 new patents.[3] The Bipartisan Policy Center noted that other Department of Energy (DOE) offices have started to adopt ARPA-E's best practices.[4]

ARPA-E has had limited success in ensuring that its awardees are able to scale their inventions from the proof-of-concept stage into commercial-scale products.[5] The Information Technology and Information Foundation (ITIF) has written frequently about the "scale-up gap" in federal innovation policies and the importance of programs that demonstrate and validate technologies at commercial or near-commercial scale under real-world conditions.[6] The average size of an ARPA-E award, on the order of $3-4 million per project, is typically not enough to address scaling challenges. To remedy this, ARPA-E launched a new Seeding Critical Advances for Leading Energy technologies with Untapped Potential (SCALEUP) program in 2020, in which successful ARPA-E projects can apply for follow-on funding to help them scale and demonstrate their technologies.[7] The awards under SCALEUP are larger than traditional ARPA-E awards, and have ranged from $2.5–19.9 million.[8] As of January 2021, ARPA-E has awarded $70 million to ten projects through the SCALEUP program, out of a total semifinalist pool of 22.[9]

Congress has continuously shown bipartisan support for the agency, expanding its budget by 46 percent over the last five years. The Energy Act of 2020 reauthorizes ARPA-E and expands its goals to include emissions reduction, improved energy efficiency, management of radioactive waste and nuclear spent fuel, and improved energy infrastructure. The bill authorizes $435 million for FY 2021, $500 million for FY 2022, $575 million for FY 2023, $662 million for FY 2024, and $761 million for FY 2025.

Figure 1 shows historical appropriations for ARPA-E for FY 2016 through FY 2021 and the FY 2022 budget request. The request includes $200 million for a new ARPA-C program that focuses on climate-related innovations to increase adaptation and resilience.[10] The orange line shows authorized funding levels from the Energy Act of 2020. The blue line shows recommended funding levels from the *Energizing America* report (see box 1).

Box 1: Recommendations for ARPA-E

The *Energizing America* report coauthored by ITIF and Columbia University's Center on Global Energy Policy offers several recommendations to maximize ARPA-E's contribution to energy innovation. Similarly, ITIF's November 2017 report "ARPA-E: Versatile Catalyst for U.S. Energy Innovation" makes recommendations to DOE and Congress to increase ARPA-E's effectiveness:

- Congress should increase ARPA-E's funding to $1 billion per year in 2025 to fulfill the target set by the 2007 National Academies *Rising Above the Gathering Storm* report.[11]
- ARPA-E's distinctive operating procedures should be maintained. While collaboration between ARPA-E and the rest of DOE is encouraged, DOE should resist exerting greater control over ARPA-E.[12]
- An ARPA-E trust fund should be established to sustain and stabilize the agency's budget. A portion of revenues from oil and gas production on federal lands should be allocated to the ARPA-E trust fund.[13]

ARPA-E RD&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 RD&D programs.

ARPA-E currently funds 393 projects across 42 active programs, which are broadly organized into 4 areas: electricity generation; efficiency and emissions; transportation and storage; and grid and grid storage.[14] 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.[15]

- **Rebellion Photonics,** based in Houston, Texas, 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.[16]

- 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.[17]

- **Bridger Photonics,** based in Bozeman, Montana, developed and commercialized a Gas Mapping LiDAR (GML) technology to detect and quantify methane leakage throughout the natural gas value chain, and eliminate the need for costly ground-crew site visits. In 2020, DOE awarded a $4.6 million grant as part of the SCALEUP program to scale and expand GML operations.[18]

Key Elements of the FY 2022 Budget Proposal[19]

The budget proposal seeks $500 million for ARPA-E, an 18 percent increase above the FY 2021 level. ARPA-E plans to release fifteen new funding opportunity announcements in areas that are not represented in the current portfolio, including:

- **Materials for carbon-neutral or carbon-negative buildings,** including those derived from feedstocks such as forest and agricultural crop residues, as well as direct use of greenhouse gases such as carbon dioxide and methane.

- **Advanced battery electrodes and conductors** that reduce charging times, increase capacity at lower weights, and utilize easily sourced materials.

- **Advanced fusion approaches and energy applications** focused on fuel options and power conversions that are less scientifically mature than the Deuterium-tritium (D-T) thermonuclear reaction.
- **SCALEUP expansion,** both in scope and in funding level, to push previous early-stage ARPA-E projects to commercialization.

Further Reading

- Varun Sivaram et al., *Energizing America: A Roadmap to Launch a National Energy Innovation Mission* (ITIF and Columbia University SIPA Center on Global Energy Policy, 2020), http://www2.itif.org/2020-energizing-america.pdf.
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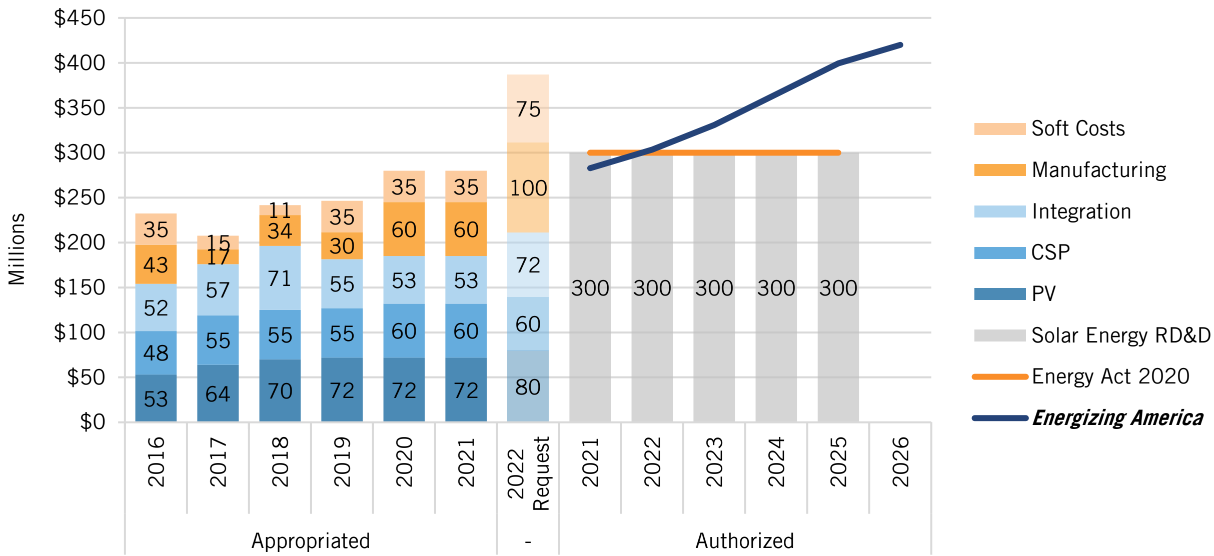
Federal Energy RD&D: Solar Energy

BY COLIN CUNLIFF AND LINH NGUYEN | JUNE 2021

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: *Energizing America* recommends ramping up solar energy research, development, and demonstration (RD&D) by 50 percent by FY 2026.[2]



What's at Stake

DOE's research programs have contributed to impressive cost declines for utility-scale solar PV (82 percent) and rooftop solar PV (64 percent) in the last 10 years, making solar energy a competitive source for electricity generation in areas of the country with good solar resources and low penetration.[3] These cost declines have led to record-breaking growth: New solar installations accounted for 43 percent of all new electricity-generating capacity installed in the United States in 2020, recording the industry's largest growth even despite the economic contraction caused by the COVID-19 pandemic.[4]

In March 2021, DOE's SunShot Initiative announced an ambitious new target to drive down the costs for utility-scale solar PV by more than half, from a current cost of 4.6 cents per kilowatt-hour ($0.046/kWh) to $0.02/kWh, by 2030.[5] The initiative builds on prior success and ratchets up the ambition of the Solar Energy program. SunShot had already achieved its 2020 goal of $0.06/kWh in 2017—three years early.[6] If DOE's new cost targets for solar PV are met, solar power could grow to supply 50 percent of U.S. electricity by 2050.[7]

SunShot's 2030 goals for commercial solar ($0.04/kWh) and residential solar ($0.05/kWh) are similarly ambitious, requiring cost reductions of more than 60 percent from 2018 benchmark costs.[8] Residential- and commercial-scale solar PV costs have come down at a slower pace as "soft" costs—such as installation labor, permitting, grid interconnection, and other non-hardware costs—remain high. In the United States, the rules and regulations for how to adopt solar from 18,000 jurisdiction and 3,000 utilities act as barriers to solar adoption and inflate soft costs.[9] For residential systems installed in the United States, soft costs accounted for 63 percent of total system costs in 2018.[10] However, soft costs in Germany (15 percent) and Australia (25 percent) were substantially lower, indicating that there is significant potential to lower soft costs in the United States.[11]

The eight 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.[12] As of 2021, 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.[13] 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.

The Energy Act of 2020 provides the first reauthorization of DOE's Solar Energy program in over a decade. The bill targets innovations in solar PV and CSP that build on DOE's past success in driving down costs and improving the performance of solar technologies. It also directs DOE to explore a range of advanced solar energy technologies, including perovskites, thin-film devices, solar heating and cooling, and integration technologies, and establishes an advanced solar energy manufacturing initiative to support the domestic solar industry as well. The bill authorizes $300 million annually for the program from FY 2021 through FY 2025.[14]

Figure 1 shows historical DOE investment in solar energy RD&D by subprogram, for FY 2016 through FY 2021, and the FY 2022 budget request. The orange line shows authorized funding levels from the Energy Act of 2020. The blue line shows recommended funding levels from the *Energizing America* report, which envisions a ramp-up in funding of 50 percent over the next five years (see box 1).

Box 1: An Innovation Agenda for Solar

The *Energizing America* report co-authored by the Information Technology and Innovation Foundation (ITIF) and Columbia University's Center on Global Energy Policy offers several recommendations to accelerate solar energy innovation. Similarly, ITIF's December 2020 report "An Innovation Agenda for Advanced Renewable Energy Technologies" makes recommendations to DOE and Congress to maximize the effectiveness of DOE's solar energy programs:

- Congress should ramp up funding for solar energy RD&D by 50 percent over the next five years to ensure DOE can address a full range of technology challenges and meet its innovation targets for solar energy.[15]

- Congress and DOE should create a new solar fuels program that both supports the direct conversion of sunlight to synthetic fuels in the applied solar energy office and builds on the basic research from the Joint Center for Artificial Photosynthesis in the Office of Science.[16]
- Congress should increase funding for DOE's soft costs team and programs that support balance-of-systems hardware, such as its work in power electronics, given the outsized impact of these expenses on total solar energy cost.[17]
- DOE should support the demonstration of microgrids and autonomous energy systems with high levels of solar penetration, such as the pilot "energy shed" management systems proposed by the Senate Appropriations Committee.[18]
- DOE should partner with the Department of Defense to develop the next generation of solar PV technologies, including low-cost and scalable manufacturing technologies.[19]

Solar Energy RD&D Subprograms

RD&D in the Solar Energy program is spread across five subprograms:[20]

- **Photovoltaics** funds RD&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** focuses on component-level RD&D in solar collectors, receivers, heat-transfer fluids, power conversion, and thermal-energy storage, as well as on the 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 costs 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 2022 Budget Proposal[21]

The budget proposal seeks $386.58 million for the Solar Energy program, a 38 percent boost from FY 2021 enacted levels. Some highlights include:

- **A 115 percent increase in the Balance of Systems Soft Cost Reduction subprogram.** Soft costs are the non-hardware costs of installing solar projects, including permitting, inspection, and financing. Soft costs accounted for 64 percent of total system costs of residential PV systems, 55 percent of commercial PV systems, and 35 percent of utility-scale systems in 2020.[22] Reaching DOE's solar cost targets will require significant reductions in soft costs.

- **A 67 percent increase in the Manufacturing and Competitiveness subprogram,** including an additional round of funding for the American-Made solar prize competition to seed new solar technologies, and a $35.9 million boost in funding for solar manufacturing and value-chain RD&D. The United States' share of global solar PV manufacturing is very small even though tariffs have been imposed on imports on multiple occasions.
- **A 35 percent increase in the Systems Integration subprogram,** with increased funding in solar microgrids and hybrid systems that integrate solar with other technologies.
- **An 11 percent increase in the Photovoltaic Technologies subprogram,** including 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 for projects that improve the durability of balance of systems components (i.e. inverters).
- **No significant change in funding for the Concentrating Solar Power subprogram.** Industrial applications RD&D will receive a small increase in funding to support the development of novel solar technologies to produce ammonia and hydrogen.

Further Reading

- Varun Sivaram et al., *Energizing America: A Roadmap to Launch a National Energy Innovation Mission* (ITIF and Columbia University SIPA Center on Global Energy Policy, 2020), http://www2.itif.org/2020-energizing-america.pdf.
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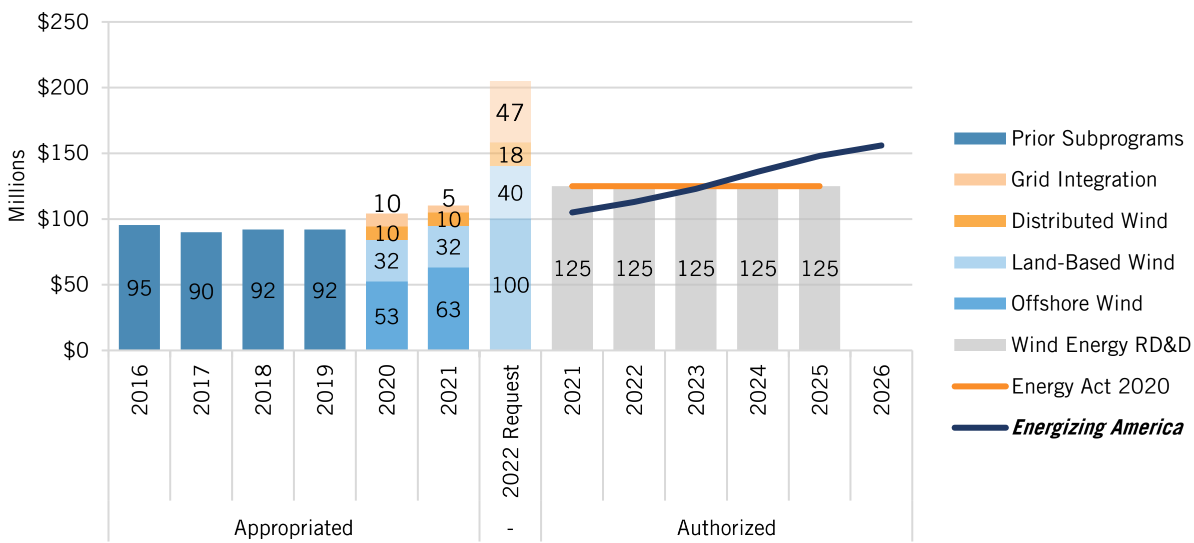
Federal Energy RD&D: Wind Energy

COLIN CUNLIFF AND LINH NGUYEN | JUNE 2021

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: *Energizing America* recommends ramping up wind energy research, development, and demonstration (RD&D) by 50 percent by FY 2026.[2]



What's at Stake

DOE's Wind Energy program has contributed to 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 decreased from 55 cents per kilowatt-hour ($0.55/kWh) in 1980 to a national average for new wind projects built in 2018 of just $0.034/kWh, enabling the expansion of wind power to more than 40 states.[3] Despite the economic contraction caused by the COVID-19 pandemic, wind power installations reached a record of almost 17 gigawatts (GW) of capacity in 2020.[4] Wind power now accounts for 8 percent of U.S. electricity generation, up from less than 1 percent a decade ago.[5]

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.[6]

The nascent offshore wind industry is beginning to take off, with 28,521 megawatts (MW) of new offshore wind capacity in the development and operational pipeline as of 2019, of which 6,439 MW have begun permitting processes for construction.[7] In 2019, DOE, along with the New York State Energy Research and Development Authority (NYSERDA), committed $20.5 million to form a National Offshore Wind Research and Development Consortium. NYSERDA agreed to match the DOE commitment and has released the solicitation for an award.[8] Offshore wind could present a low-carbon energy alternative for the 28 coastal and Great Lakes 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 provide investors with greater confidence in the growing array of energy projects in U.S. waters.[9]

Over 58 percent of offshore wind resources are located in areas with deep waters, primarily off the western coastal states, where fixed-bottom wind turbines are not practical.[10] Innovative floating offshore wind turbines, which are at an early stage of development, can enable access to deeper water depths and expand viable areas for offshore wind development. DOE has provided $10.7 million in funding for University of Maine's New England Aqua Ventus I, a floating offshore wind demonstration project of up to 12 MW off Monhegan Island, Maine.[11] Successful demonstration of the first utility-scale floating offshore wind project in federal waters could increase confidence from investors that the technology works as intended, potentially catalyzing greater private investment.

In March 2021, the Biden administration announced an ambitious new target to deploy 30 GW of offshore wind by 2030 and 110 GW by 2050. To reach this goal, DOE's Loan Program Office (LPO) expects to offer $3 billion in loan guarantees for offshore wind suppliers, developers, and other financing partners.[12] DOE loan guarantees are an important tool to bridge the innovative energy financing gap and backstop the risks commercial lenders are unwilling to bear. LPO has previously provided $1.6 billion for onshore wind projects, unlocking 1,000 MW of onshore wind capacity.[13]

The Energy Act of 2020 provides the first reauthorization of DOE's Wind Energy program in more than a decade, and focuses on innovation in onshore, offshore, distributed, and off-grid technologies. The bill authorizes projects that validate and demonstrate transformational wind energy technologies; research wind turbine integration in hybrid energy systems; and support the operation of offshore research facilities, including offshore support-structure testing facilities. The bill authorizes $125 million annually for FY 2021 through FY 2025.[14]

Figure 1 shows historical DOE investment in wind energy RD&D by subprogram, for FY 2016 through FY 2021, and the FY 2022 budget request. Prior to FY 2020, DOE structured its Wind Energy subprograms differently, so FY 2016 to 2019 subprograms (dark blue in figure 1) are not directly comparable. DOE made the change to the current structure to better comply with congressional direction. The orange line shows authorized funding levels from the Energy Act of 2020. The blue line shows recommended funding levels from the *Energizing America* report, which envisions a ramp-up in funding for wind energy RD&D of 50 percent over the next five years (see box 1).

Box 1: An Innovation Agenda for Wind

The *Energizing America* report co-authored by the Information Technology and Innovation Foundation (ITIF) and Columbia University's Center of Global Energy Policy offers several recommendations to drive wind energy innovation. Similarly, ITIF's December 2020 report "An Innovation Agenda for Advanced Renewable Energy Technologies" makes recommendations to DOE to improve DOE's Wind Energy programs:

- Congress should ramp up funding for wind energy RD&D by 50 percent over the next five years to ensure DOE can address the full range of technology challenges and meet its innovation targets for wind energy.[15]
- DOE should set a more ambitious 2030 cost target for offshore wind, currently set at $51/MWh, by 2030. The National Renewable Energy Laboratory's (NREL) 2020 Annual Technology Baseline suggests that costs could be reduced to less than $45/MWh for most offshore wind resource classes by 2030 in an advanced technology innovation scenario.[16]
- Congress and DOE should increase RD&D support for projects that improve manufacturing methods and increase turbine efficiency.[17]
- DOE should partner with wind developers to demonstrate novel wind turbine designs. Companies are risk averse and are typically unwilling to initiate the demonstration of immature wind technologies without federal support.[18]
- DOE should invest with industrial partners in cost-shared floating wind demonstration projects to ramp up industry adoption.[19]
- DOE should support the demonstration of microgrids and hybrid energy systems that integrate more power from wind energy systems.[20]

Wind Energy RD&D Subprograms

RD&D in the Wind Energy program is divided into four subprograms:[21]

- **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** RD&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, while seeking 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. [22]

- **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 assessments.

- **Systems Integration**, which includes the former Grid Integration & Analysis program, promotes RD&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.

Key Elements of the FY 2022 Budget Proposal[23]

The budget proposal seeks $204.87 million for the Wind Energy program, an 86 percent boost from FY 2021 enacted levels. Some highlights include:

- **A 59 percent increase in Offshore Wind,** including funding for competitively-awarded projects to improve offshore wind resource characterization and forecasting; for offshore development and demonstration projects, including floating turbine, platform, and wind farm controls; to improve the recycling and recovery of critical materials; for research to evaluate the environmental impacts of floating and fixed-bottom offshore wind projects; and for advanced materials manufacturing RD&D to reduce the lifecycle costs and improve the performance of wind turbine components. The Offshore Wind subprogram aims to reduce the levelized cost of energy for offshore wind from $0.08/kWh in 2019 to $0.05/kWh by 2030.
- **A 26 percent increase in Land-Based Wind,** with continued support for test facilities at NREL Flatirons Campus and Sandia's SWiFT facility, which would be kept in standby mode; continued funding for adaptive load control technologies within the Big Adaptive Rotor initiative; increased funding for environmental and siting R&D to support technologies that minimize the impacts of wind development on grouse species; and continued support for the American Wake Experiment (AWAKEN), a planned international wake observation and validation campaign for wind-farm modeling.
- **An 837 percent increase in Systems Integration**, including new efforts to identify transmission infrastructure needs for offshore wind, develop new energy storage technologies in support of the Energy Storage Grand Challenge, and validate and demonstrate hydrogen production with wind energy.

- **A 78 percent increase in Distributed Wind,** with continued funding for testing and reliability; the launch of the Wind Innovations for Rural Economic Development (WIRED) networks to reduce the soft costs and overcome barriers to deployment in rural communities; continued support for the Microgrids, Infrastructure, Resilience, and Advanced Controls Launchpad (MIRACL) focused on the integration and control of distributed wind hybrid systems; and new funding to support the inclusion of wind in the Energy Transitions Initiative Partnership Project.

Further Reading

- Varun Sivaram et al., *Energizing America: A Roadmap to Launch a National Energy Innovation Mission* (ITIF and Columbia University SIPA Center on Global Energy Policy, 2020), http://www2.itif.org/2020-energizing-america.pdf.
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The Information Technology and Innovation Foundation (ITIF) is an independent, nonprofit, nonpartisan research and educational institute focusing on the intersection of technological innovation and public policy. Recognized by its peers in the think tank community as the global center of excellence for science and technology policy, 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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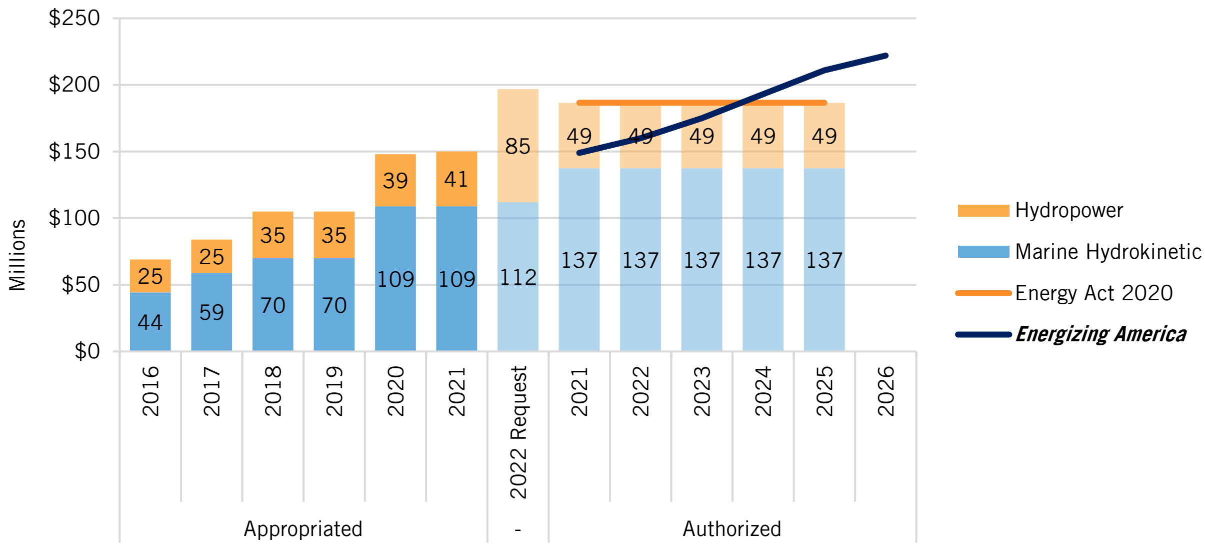
Federal Energy RD&D: Water Power

BY COLIN CUNLIFF AND LINH NGUYEN | JUNE 2021

The Department of Energy's (DOE) Water Power program supports research, development, and demonstration (RD&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: *Energizing America* recommends ramping up funding for water power RD&D by nearly 50 percent by FY 2026.[2]



What's at Stake

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 2020.[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. DOE's 2016 *Hydropower Vision* report identifies 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 potential 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 by 2030.[5] DOE recently launched the Hydropower and Water Innovation for a Resilient Electricity System (HydroWIRES) to improve both conventional and pumped-storage hydropower 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 Lakes states, additional cost reductions are needed to make them cost competitive with other sources of electricity.

Additionally, marine energy can provide new capabilities, such as onboard energy generation and remote recharging, in areas far from land-based power grids. In April 2019, DOE released a new report, *Powering the Blue Economy*, that identifies non-grid applications and opportunities for marine renewable energy to tap into new markets and provide new energy services.[8] However, the United States lags behind nations that have invested more heavily in developing marine energy technologies. For example, the EU established a European Marine Energy Centre that enables prototypes up to 1 MW to be tested in open waters. The United States has no test beds that are comparable in scale.[9]

The Energy Act of 2020 provides the first reauthorization of DOE's Water Power program in more than a decade. The law authorizes activities that support the development of new technologies for pumped storage, constructed waterways, new stream-reach development, and modular and small dams. Moreover, the law authorizes projects that advance new pumped storage hydropower technologies, including systems with adjustable speed, modular systems, and alternative closed-loop systems. To accelerate innovation in marine technologies, DOE will continue supporting existing National Marine Energy Centers and create new centers that focus on in-water testing and demonstration. The bill authorizes $186.6 million annually for FY 2021 through FY 2025, including $137 million for marine energy and $49 million for hydropower RD&D activities.[10]

Figure 1 shows historical DOE investment in water power RD&D by subprogram, for FY 2016 through FY 2021, and the FY 2022 budget request. The orange line shows authorized funding levels from the Energy Act of 2020. The blue line shows recommended funding levels from the *Energizing America* report, which envisions a ramp-up to a 50 percent increase in water power technologies RD&D by FY 2026 (see box 1).

Box 1: An Innovation Agenda for Water Power

The *Energizing America* report co-authored by the Information Technology and Innovation Foundation (ITIF) and Columbia University's Center on Global Energy Policy offers several recommendations to accelerate innovation in water power. Similarly, ITIF's December 2020 report "An Innovation Agenda for Advanced Renewable Energy Technologies" makes recommendations to DOE and Congress:

- Congress should ramp up funding for MHK and advanced hydropower technologies by 50 percent over the next five years to address RD&D needs and meet the innovation targets outlined in the *Hydropower Vision* and *Powering the Blue Economy* roadmaps.[11]

- DOE should establish a modeling and computational program to explore the integration of new components to hydropower infrastructure, develop cheaper and more durable components, and improve fleet performance to increase generation capacity and offer flexibility to complement intermittent renewable energy sources.[12]
- DOE should support the demonstration of innovative and sustainable hydropower designs and establish hydropower RD&D test facilities that demonstrate environmental protection technologies to minimize impacts to marine ecosystems.[13]
- DOE should support RD&D programs that reduce costs for marine energy technologies. Programs that involve prize competitions could be well suited for marine energy, given its technological immaturity and uncertainties in design.[14]

Water Power RD&D Subprograms

RD&D in the Water Power program is spread across two subprograms:[15]

- **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 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. An MHK open-water wave-energy test facility currently being developing—to be begin operation between 2021 and 2022—will allow testing and validation of industry-developed MHK energy-conversion components and systems.[16] The subprogram is also exploring the ability of marine energy to provide non-grid energy services in areas where access to an electric grid is limited.[17]

Key Elements of the FY 2022 Budget Proposal[18]

The budget proposal seeks $196.56 million for the Water Power program, a 31 percent boost from FY 2021 enacted levels. Some highlights include:

- **A 3 percent increase in the Marine Energy Technologies subprogram,** including increased funding for advanced materials and manufacturing; increased funding to advance technologies from the Waves to Water and Ocean Obs prize competitions; continued funding for the development and testing of marine hydro-kinetic systems and components, as well as wave-powered desalination systems; and continued support of the Testing Expertise and Access for Marine Energy Research (TEAMER) initiative, a campaign to provide developers with access to marine energy testing facilities across the nation.

- **A 106 percent increase in the Hydropower Technologies subprogram,** including increased funding for the HydroWIRES initiative to support the development and testing of innovative pumped-storage hydropower technologies; funding to support a hydropower-specific program at Oak Ridge National Laboratory's Manufacturing Demonstration Facility to reduce the manufacturing costs of new hydropower technologies; and new funding for research into novel water infrastructure sensors to detect leakage and evaporative losses to promote water conservation.

Further Reading

- Varun Sivaram et al., *Energizing America: A Roadmap to Launch a National Energy Innovation Mission* (ITIF and Columbia University SIPA Center on Global Energy Policy, 2020), http://www2.itif.org/2020-energizing-america.pdf.
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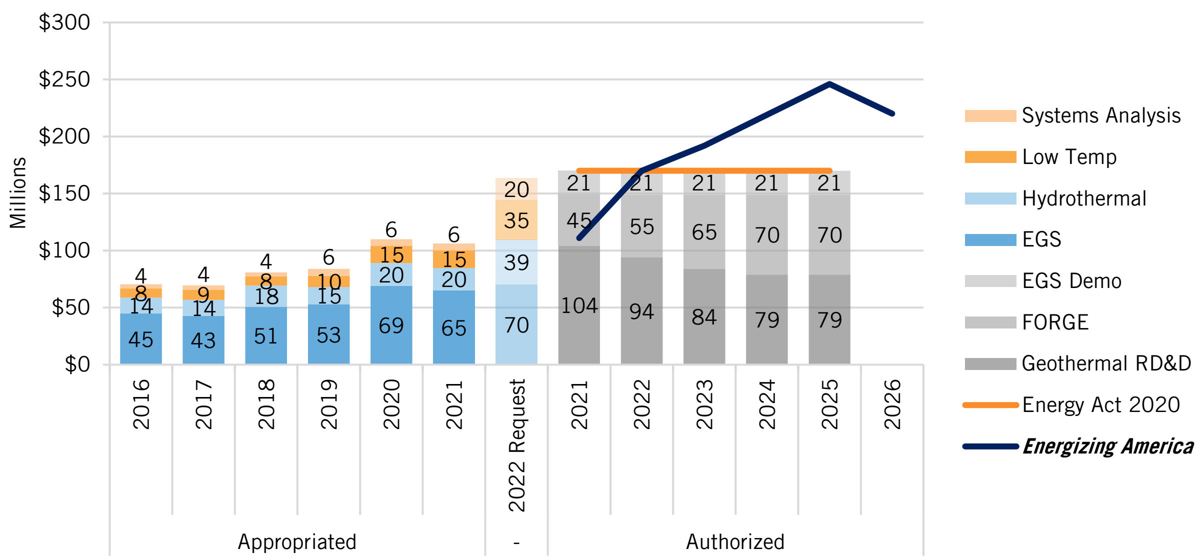
Federal Energy RD&D: Geothermal Technologies

BY COLIN CUNLIFF AND LINH NGUYEN | JUNE 2021

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, development, and demonstration (RD&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: *Energizing America* recommends doubling investment in geothermal technologies by FY 2026.[2]



What's at Stake

There is a vast source of untapped energy that dwarfs the current U.S. installed capacity of about 3.8 gigawatts (GW) of geothermal energy. The Department of Energy's (DOE) 2019 report *GeoVision: Harnessing the Heat Beneath Our Feet,* finds that technological improvements and cost reductions could increase geothermal capacity more than fifteenfold to 60 gigawatts (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 2 to 5 kilometers, thus requiring new exploration technologies and tools to reduce the near-term costs and risk of development. DOE set a goal of reducing the cost of electricity from EGS to 6 cents per kilowatt-hour ($0.06/kWh) by 2050, which would make this technology competitive with other forms of 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 finds that the market potential for geothermal heat pumps is equivalent to supplying heating and cooling to 28 million households, or 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 RD&D to harness them more effectively, develop improved methods to stimulate new resources, and characterize and model subsurface stress and other reservoir properties. An increase in RD&D funding could enable DOE to unlock promising opportunities to advance geothermal technologies.

The Energy Act of 2020 provides the first reauthorization of DOE's Geothermal Technologies program in more than a decade. The law directs DOE to support the development of up to three Frontier Observatory for Research in Geothermal Energy (FORGE) sites to study EGS; requires DOE to demonstrate four EGS projects at potentially commercially viable locations across the nation; establishes a research program on geothermal heat pumps; directs the U.S. Geological Survey to update its geothermal resource assessments; and establishes a program that to advance geothermal computing and reservoir modeling. The Act authorizes $170 million annually for FY 2021 through FY 2025.[6] Of the total authorized funding, $21 million is authorized for EGS demonstrations annually for FY 2021 through FY 2025. FORGE activities are also authorized $45 million for FY 2021, $50 million for FY 2022, $65 million for FY 2023, $70 million for FY 2024, and $70 million for FY 2025 of the total authorized funding.

Figure 1 shows historical DOE investment in geothermal RD&D by subprogram, for FY 2016 through FY 2021, and the FY 2022 budget request. The orange line shows authorized funding levels from the Energy Act of 2020. The blue line shows recommended funding levels from the *Energizing America* report, which recommends doubling investment in geothermal RD&D by FY 2026 (see box 1).

Box 1: An Innovation Agenda for Geothermal

The *Energizing America* report co-authored by the Information Technology and Innovation Foundation (ITIF) and Columbia University's Center on Global Energy Policy offers several recommendations to accelerate innovation in geothermal technologies. Similarly, ITIF's December 2020 report "An Innovation Agenda for Advanced Renewable Energy Technologies" makes recommendations to DOE and Congress:

- Congressional appropriators should provide full funding to develop the three FORGE pilot sites and the four EGS demonstration projects that were authorized in the Energy Act of 2020.

- Congress should direct the Geothermal Technologies Office to expand RD&D collaboration with DOE's Office of Fossil Energy to develop technologies and processes using unconventional oil, gas drilling, and simulation techniques to address the technical challenges of EGS.[7]

- Congress should provide additional funding for geothermal RD&D of geothermal heat pumps and district heating systems through prize competitions or cost-share programs.[8]
- Congress and DOE should support the development of high-temperature laboratory facilities to enable super-hot-rock EGS testing.[9]
- DOE should collaborate with private companies through cost-share agreements to build commercial EGS demonstration projects.[10]

Geothermal Technologies RD&D Subprograms

Geothermal RD&D is divided into four subprograms:[11]

- **Enhanced Geothermal Systems** 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 FORGE site in Utah, a facility wherein industry and government researchers can test and validate innovative EGS technologies in a deep-rock environment.[12]
- **Hydrothermal Research and Development (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 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.[13]

Key Elements of the FY 2022 Budget Proposal[14]

The budget proposal seeks $163.76 million for the geothermal technologies program, a 54 percent boost from FY 2021 enacted levels. Some highlights include:

- **Decrease in 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. No funding is requested for Advanced Wellbore Completions for EGS Longevity, which focuses on alternative completion techniques. Funding is requested for an additional competitive R&D solicitation on new EGS technologies and techniques.

- **An 8 percent increase in the EGS subprogram**, including increased funding for exploration and characterization R&D, which supports the near-field EGS demonstration projects and a prize competition to develop geophones that can reliably track reservoir growth during EGS simulations under high temperatures. The request also includes funding to establish the Geothermal Energy from Oil and Gas Demonstrated Engineering (GEODE), a consortium to leverage oil and gas assets and expertise to the geothermal field.
- **A 96 percent increase in the Hydrothermal subprogram,** including new funding for the Drilling Technology Demonstration Campaign, which will enable field demonstrations of innovative drilling technologies, including those adapted from the oil and gas industry, to reduce the costs and risks of drilling and attract future private investment and use.
- **A 131 percent increase in the Low Temperature subprogram,** including funding for the Energy Storage Grand Challenge to validate and demonstrate new thermal energy storage technologies; initial funding for the Community Geothermal Heating and Cooling Technical Assistance and Deployment initiative to demonstrate and deploy community-scale direct-use geothermal energy systems; for the Federal Partnerships for Geothermal Installations initiative, in collaboration with the Federal Energy Management Program, to drive geothermal projects on Federal sites; and for the Next Generation Connected Communities initiative, in collaboration with the Building Technologies Office, to demonstrate geothermal energy storage and community geothermal energy resource.
- **A 226 percent increase in the Data, Modeling, and Analysis subprogram,** including funding for geothermal-specific grid research and analysis.

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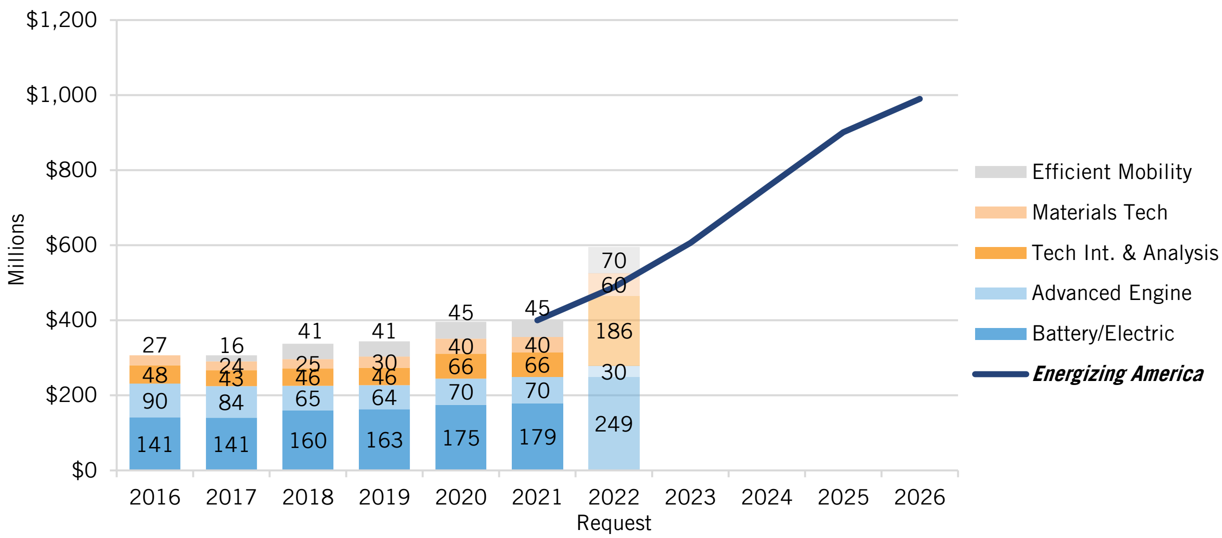
Federal Energy RD&D: Vehicle Technologies

BY COLIN CUNLIFF AND LINH NGUYEN | JUNE 2021

The transportation sector is the largest source of U.S. greenhouse gas emissions, accounting for 29 percent of all carbon pollution in 2019.[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] By investing in research, development, and demonstration (RD&D) to use conventional fuels more efficiently and develop domestically produced electric vehicle (EV) technologies, the Vehicle Technologies Office (VTO) works to keep prices low for consumers, improve national energy security, and enhance environmental performance.[3] VTO also leads the Department of Energy's (DOE) research in autonomous and connected vehicles and intelligent transportation systems, which have the potential to improve transportation services while reducing greenhouse gas emissions.[4]

Figure 1: *Energizing America* recommends increasing funding by 150 percent by FY 2026.[5]



What's at Stake

The world has begun the transition to EVs. Global EV sales reached over 3 million in 2020, up 40 percent from the 2.1 million sold in 2019, a record increase in new sales despite the economic contraction caused by the COVID-19 pandemic.[6] In the United States, EV sales were 4 percent higher than in 2019 in a car market that shrank by 15 percent.[7] Major automakers are rapidly increasing the range of EV models they offer. General Motors, the largest U.S.-based automaker, announced in January 2021 that it aspires to an "all-electric future [and] … to eliminate tailpipe emissions from new light-duty vehicles by 2035."[8]

To accelerate the transition to EVs and help domestic automakers capture this growing global market, VTO has set technology cost and performance targets for EVs and the batteries that power them, including 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. These targets were chosen to make EVs competitive with internal combustion engine (ICE) vehicles. At a battery cost of $100/kWh, the total cost of ownership of an EV—purchase price plus maintenance and fuel costs over the lifetime of the vehicle—reaches cost-parity with ICE vehicles. And at a battery cost of $60/kWh, the upfront purchase price of an EV reaches parity with ICE vehicles.

But these targets may not be sufficiently aggressive: BloombergNEF's *Electric Vehicle Outlook* projects battery costs to reach $100/kWh by 2024, while IHS Markit anticipates reaching the $100/kWh milestone in 2023.[9] The National Academies of Sciences, Engineering, and Medicine found that batteries for EVs will reach $100/kWh in the 2023–2025 range, and could reach $60/kWh by 2030.[10]

DOE should set more-ambitious innovation targets—and Congress should appropriate commensurate funding levels—in order to help domestic automakers and battery manufacturers reclaim global leadership in EVs. China is currently leading the world in EV deployment, accounting for more than half of total global production and sales, while the European Union is moving quickly to catch up and secure its own EV supply chain.[11] Greater investment in battery and electrification RD&D is needed to 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.[12] Long-haul trucking is a key "hard-to-decarbonize" transportation subsector that is more challenging to electrify due to the need for high-energy-density fuels. Improving efficiency is one of the few good near-term options for lowering energy costs and reducing carbon emissions in this sector.[13]

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. The Energy Efficient Mobility Systems (EEMS) subprogram leads DOE's work in Connected and Autonomous Vehicles (CAVs), which integrate intelligence and sensing capabilities to enable vehicle operation with little human intervention and increased connectivity between vehicles and traffic signals. By optimizing traffic signaling and decreasing accidents caused by human error, CAVs have the potential to reduce congestion, fuel consumption, and emissions.[14]

The Energy Act of 2020 provides the first reauthorization of DOE's Sustainable Transportation program—which includes VTO, the Bioenergy Technologies Office, and the Hydrogen and Fuel Cell Technologies Office—in over a decade. The bill authorizes $830 million for FY 2021, $855 million for FY 2022, and $880 million for FY 2023 for Sustainable Transportation, but does not specify the amount to be allocated to each office.[15]

Figure 1 shows historical DOE investment in vehicles technologies RD&D by subprogram, for FY 2016 through FY 2021, and the FY 2022 budget request. The blue line shows recommended funding levels from the *Energizing America* report (see box 1). Because transportation makes up a disproportionately small share of the federal energy RD&D budget—transportation accounts for 29 percent of U.S. greenhouse gas emissions but only 16 percent of DOE's portfolio—*Energizing*

America recommends a fast ramp-up to 150 percent above FY 2020 levels over the next five years.[16]

Box 1: An Innovation Agenda for Vehicles Technologies

The *Energizing America* report co-authored by the Information Technology and Innovation Foundation (ITIF) and Columbia University's Center on Global Energy Policy offers several recommendations to DOE and Congress to accelerate innovation in vehicles technologies. Similarly, ITIF's 2018 report "Innovation Agenda for Deep Decarbonization" makes recommendations for harder-to-decarbonize transportation sectors, include aviation, long-distance trucking, and marine shipping:

- Congress should ramp up investment in vehicle technologies RD&D by 150 percent over the next five years.[17] This increase is needed to rebalance the research portfolio and make up for historical underinvestment. Transportation is now the largest-emitting sector, producing 29 percent of U.S. greenhouse gas emissions, but accounts for only 16 percent of DOE's portfolio.[18]
- Congress should double investment in RD&D of artificial intelligence with energy applications across the federal government, including DOE programs in advanced grid RD&D and Information Technology and Services (ITS).[19]
- DOE should accelerate the ambition of its cost target for advanced batteries. DOE's current goal to reduce the cost of batteries for EVs to $100/kWh by 2028 is not ambitious enough. But multiple analyses from the National Academies, Bloomberg New Energy Finance, and IHS Markit suggests that this target could be achieved by 2023–2025.[20]
- DOE should increase RD&D of fast-charging EVs, as slow charging times have been a barrier in EV deployment.[21]
- DOE should launch a SuperTruck III program to double freight-hauling efficiency of heavy-duty Class 8 trucks by 2025.[22]
- DOE and the Department of Transportation should create new programs targeting shipping, aviation, and energy management and electrification at ports and airports, which have not been a focus in past federal transportation RD&D programs.[23]

Vehicle Technologies RD&D Subprograms

RD&D in the Vehicle Technologies program is distributed across six subprograms:[24]

- **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 RD&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 and Fuel Technologies Research and Development (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 RD&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 (AVTC) and other workforce development programs.

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

Key Elements of the FY 2022 Budget Proposal[25]

The budget proposal seeks $595 million for the Vehicle Technologies program, a 49 percent boost from FY 2021 enacted levels. Some highlights include:

- **A 39 percent increase in the Battery and Electrification Technologies subprogram,** including a $65.5 million increase in funding for battery R&D; funding for battery development work through the Battery500 R&D Consortium; a $2 million increase for electric drive R&D; and a $2.5 million increase for electrification R&D, focusing on developing smart charging, extreme fast charging, and wireless charging technologies.
- **A 57 percent reduction of the Advanced Engine & Fuel Technologies R&D subprogram,** 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 56 percent increase in the Energy Efficient Mobility Systems subprogram,** including a $20 million investment in clean energy mobility solutions for underserved communities and a $4 million increase in computational modeling and simulation.
- **A 50 percent increase in the Materials Technology R&D subprogram,** including funding for a new research effort on non-exhaust emissions from tire wear, brake wear, road wear, and stirred-up dust, which contribute to particulate matter (PM2.5) pollution. Funding will also increase for research on electrical conductivity, thermal conductivity, magnetic materials, and high-temperature operations that limit advances in wireless charging and electric powertrains.
- **A 200 percent increase in the Technology Integration subprogram,** including funding for SuperTruck III demonstration projects; new funding for charging infrastructure

demonstration projects; and new funding for smart charging vehicle-grid integration demonstration projects.

- **No change to the Data, Modeling, and Analysis subprogram.**

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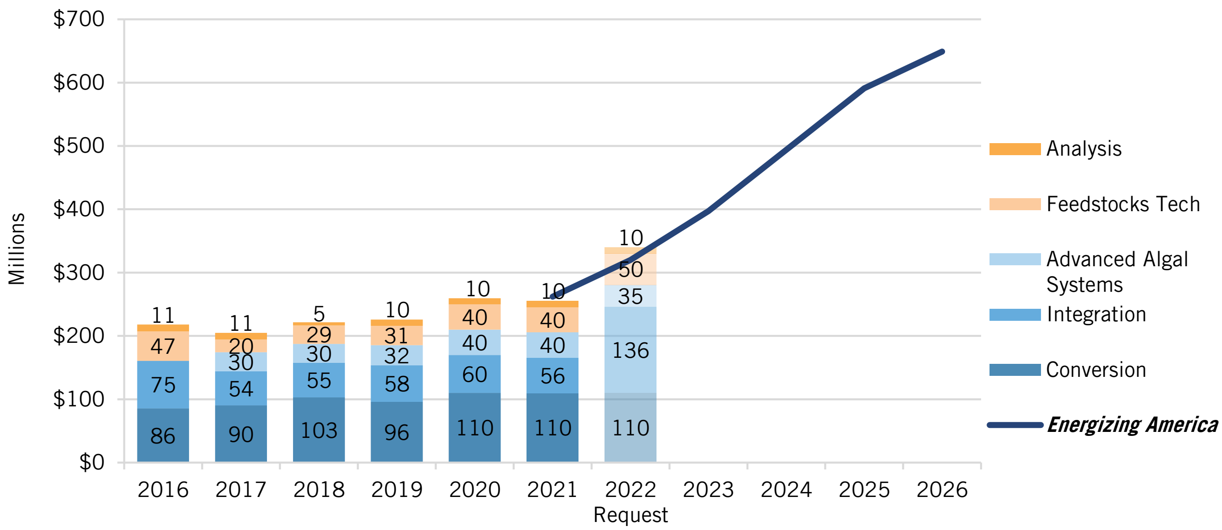
Federal Energy RD&D: Bioenergy Technologies

BY COLIN CUNLIFF AND LINH NGUYEN | JUNE 2021

The Department of Energy's (DOE) Bioenergy Technologies Office (BETO) focuses on research, development, and demonstration (RD&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 RD&D focus is on creating "drop-in" biofuels that are compatible with both 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: *Energizing America* recommends ramping up funding by 150 percent by FY 2026.[2]



What's at Stake

The United States has the potential to sustainably produce 1 billion dry tons of nonfood biomass resources by 2030 without disrupting agricultural markets for food and animal feed.[3] This feedstock could be converted into 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—each year.[4] In addition, enough algae, which grows quickly and consumes waste, could be harvested to provide another 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] A number of other 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.

The Energy Act of 2020 provides the first reauthorization of DOE's Sustainable Transportation program—which includes BETO, the Vehicle Technologies Office, and the Hydrogen and Fuel Cell Technologies Office—in over a decade. The bill authorizes $830 million for FY 2021, $855 million for FY 2022, and $880 million for FY 2023 for Sustainable Transportation—although it does not specify the amount to be allocated to each office.[7]

Figure 1 shows historical DOE investment in bioenergy technologies RD&D by subprogram, for fiscal years 2016 through 2021, and the FY 2022 budget request. The blue line shows recommended funding levels from the *Energizing America* report (see box 1). Because bioenergy plays such an important role in addressing many harder-to-abate transportation and industrial sectors, *Energizing America* recommends a fast ramp-up to 150 percent above FY 2020 levels over the next five years.

Box 1: An Innovation Agenda for Bioenergy Technologies

The *Energizing America* report co-authored by the Information Technology and Innovation Foundation (ITIF) and Columbia University's Center on Global Energy Policy offers several recommendations to accelerate innovation in bioenergy technologies. Similarly, ITIF's September 2020 report "Gene Editing for the Climate: Biological Solutions for Curbing Greenhouse Gas Emissions" makes recommendations to DOE and Congress:

- Congress should ramp up investment in bioenergy and biomanufacturing RD&D by 150 percent over the next five years.[8] This increase is needed to make up for historical underinvestment and help scale promising bio-technologies from the lab to commercial scale.
- Congress and DOE should create a permanent research program to develop negative emissions technologies such as bioenergy with carbon capture and storage (BECCS).[9]
- Congress should allow farmers and state and local governments to take advantage of the Section 45Q tax credit for carbon capture projects that use gene-edited technologies.[10] The 45Q tax credit could complement DOE's BECCS programs by expanding the market for BECCS technologies.
- DOE and the United States Department of Agriculture (USDA) Biofuels program should support the development of drop-in fuels for aviation, shipping, and other hard-to-electrify transportation sectors.[11]
- DOE should expand its recent initiative to support research into gene-editing tools that improve cellulosic biomass processing to make switchgrass, sorghum, and even trees become economical materials for biofuels production. There is also considerable potential for gene-edited improvements in harnessing algae to produce energy-dense compounds such as butanol.[12]

Bioenergy Technologies RD&D Subprograms

RD&D in the Bioenergy program is distributed across these five subprograms:[13]

- **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 group of eight national laboratories focused on feedstock handling, preprocessing, and conversion opportunities in order to reduce the sales price of biofuel.
- **Advanced Algal Systems** supports RD&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 evaluations to inform BETO decisions regarding the future direction and scope of its RD&D portfolio.

Key Elements of the FY 2022 Budget Proposal[14]

The budget proposal seeks $340 million for the Bioenergy program, a 33 percent boost from FY 2021 enacted levels. Some highlights include:

- **A 144 percent increase in System Development and Integration,** including a $77.5 million increase in funding to scale up RD&D for biofuel production, with a focus on aviation fuels and waste-to-energy technologies.
- **A 13 percent reduction in Advanced Algal Systems,** including a $5 million reduction in funding for research on direct air capture technologies. 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.
- **A 25 percent increase in Feedstock Technologies,** including increased funding for national laboratory research and development (R&D) activities focused on soil carbon sequestration, bioenergy with carbon sequestration (BECCS), and other sustainable agriculture technologies; continued funding for competitive research to reduce the costs of feedstock logistics; continued funding for the Feedstock-Conversion Interface

Consortium (FCIC); continued funding for R&D on harvest logistics and quality assurance, biomass densification, and biomass analytic;

- **No change in total funding for Conversion Technologies R&D,** including funding increases for bio-processing R&D, catalyst R&D, and co-products R&D, and a funding decrease of $26.5 million for deconstruction and synthesis R&D, an area that has been a focus in prior years.
- **No change in the Data, Modeling, and Analysis subprogram.**

Further Reading

- Varun Sivaram et al., *Energizing America: A Roadmap to Launch a National Energy Innovation Mission* (ITIF and Columbia University SIPA Center on Global Energy Policy, 2020), http://www2.itif.org/2020-energizing-america.pdf.
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The Information Technology and Innovation Foundation (ITIF) is an independent, nonprofit, nonpartisan research and educational institute focusing on the intersection of technological innovation and public policy. Recognized by its peers in the think tank community as the global center of excellence for science and technology policy, 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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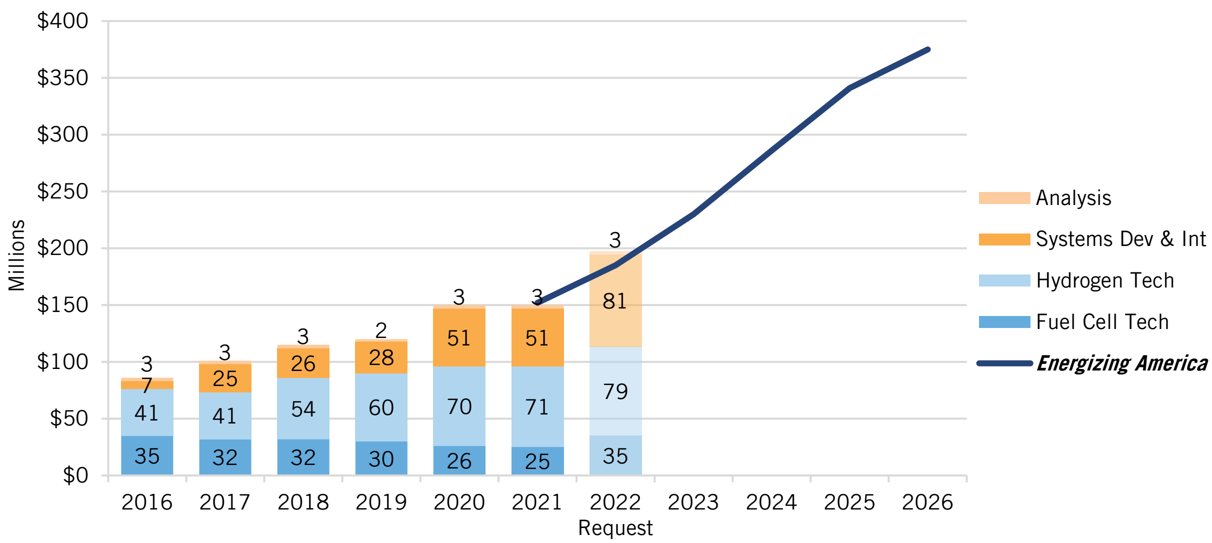
Federal Energy RD&D: Hydrogen & Fuel Cells

BY COLIN CUNLIFF AND LINH NGUYEN | JUNE 2021

Hydrogen's versatility as an energy carrier and feedstock, and its lack of greenhouse gas emissions at the point of use, makes it an attractive alternative to fossil fuels for hard-to-abate energy sectors. Hydrogen is already produced on a large scale using copious quantities of natural gas, so it is an important sector to decarbonize in any case. And its potential to help other sectors decarbonize will only be realized if clean hydrogen production is dramatically scaled up. Fuel cells convert the chemical energy of hydrogen into electricity, without emitting carbon or conventional pollutants. The Hydrogen & Fuel Cells Technologies Office (HFTO) conducts research, development, and demonstration (RD&D) on three complementary technologies: low-cost clean hydrogen production; 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: *Energizing America* recommends increasing funding by 150 percent by FY 2026.[2]



What's at Stake

Hydrogen has enormous potential to address multiple critical decarbonization challenges.[3] It 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 that have few alternative emissions-reduction solutions.[4] Because of its wide range of end uses, hydrogen can facilitate greater integration of energy systems across sectors—leading many to call for the creation of a "hydrogen economy."[5] However, realizing its potential will require continued RD&D, and early deployment support to bring down costs for production and delivery systems as well as end-use applications.

The United States currently produces 10 million metric tons per year (MMT/yr) of hydrogen (about 15 percent of global production), primarily for use in oil refining, fertilizer production, and biofuels production.[6] But current hydrogen production methods are incredibly carbon-intensive, releasing an average of 11 tons of carbon dioxide (CO_2) for every 1 ton of hydrogen.[7] Clean hydrogen production pathways include methane reforming with carbon capture and storage, water electrolysis (water splitting) using zero-carbon electricity, and biomass gasification with carbon capture and storage.

Demand for hydrogen could grow dramatically if it realizes its potential applications in hard-to-abate energy sectors. A recent report from the National Renewable Energy Laboratory (NREL) estimates the technical potential at 106 MMT/yr across a range of industrial, transportation, and energy storage applications.[8] Princeton's Net-Zero America Project found that hydrogen use could grow by more than 700 percent by 2050 in a decarbonized energy system, with growth primarily from liquid fuel synthesis, medium- and heavy-duty vehicles, industrial boilers, gas turbines for electricity generation, and steel production.[9]

The United States has historically been a world leader in the development and deployment of hydrogen production and related technologies. Over the past 20 years, the U.S. Department of Energy (DOE) has invested more than $4 billion in hydrogen production, resulting in more than 1,100 patents.[10] And the United States is home to several leading electrolyzer and hydrogen component and system manufacturers, as well as large multinational hydrogen companies.[11]

However, the United States may be ceding its early leadership in hydrogen technologies, just as electrolyzers are maturing to the point of commercial-scale deployment. The International Energy Agency (IEA) found that the average size of new electrolyzer capacity increased from 0.1 MWe in 2000–2009 to 1.0 MWe in 2015—2019, indicating a shift from small pilot and demonstration projects to commercial-scale applications.[12] This trend occurred against the backdrop of growing investment in hydrogen around the world, and declining public support in the United States. China, Japan, and the European Union have now surpassed the United States in public funding for RD&D of hydrogen technologies. And many countries are developing national hydrogen strategies and setting targets for electrolyzer deployments, which are intended to attract greater private sector investment.[13] A key question is whether this investment will occur in the United States or elsewhere.

On the end-use side, DOE's HFTO has primarily focused on hydrogen applications in transportation—specifically on fuel cell electric vehicle (FCEV) technology for light-duty cars. However, the current portfolio may be misaligned with future opportunities. Due to the recent dramatic cost declines in lithium-ion batteries, battery electric vehicles (BEVs) will likely reach cost parity with conventional gasoline-powered cars sooner than will hydrogen FCEVs. Additionally, DOE has underinvested in hydrogen applications in the harder-to-abate sectors with the greatest potential for growth.

To accelerate the development of domestic hydrogen technologies, DOE has established innovation targets for hydrogen production ($2 per kilogram) and storage ($1 per kilogram), as well as targets for FCEVs.[14] DOE's goals for light-duty FCEVs 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.[15]

The Energy Act of 2020 provides the first reauthorization of DOE's Sustainable Transportation program—which includes Hydrogen and Fuel Cells Technologies, the Bioenergy Technology Office (BETO), and the Vehicle Technologies Office (VTO)—in over a decade. The bill authorizes $830 million for FY 2021, $855 million for FY 2022, and $880 million for FY 2023 for Sustainable Transportation, but does not specify the amount to be allocated to each office.

Figure 1 shows historical DOE investment in hydrogen and fuel cells RD&D by subprogram, for FY 2016 through FY 2021, and the FY 2022 budget request. DOE merged the Hydrogen Fuel and Hydrogen Infrastructure subprograms into a single Hydrogen Technologies subprogram in its FY 2021 budget request. DOE also merged the Technology Acceleration and Safety, Codes, and Standards subprograms into a single Systems Development and Integration subprogram. The blue line shows recommended funding levels from the *Energizing America* report (see box 1). Because hydrogen plays such an important role in addressing multiple harder-to-abate sectors, *Energizing America* recommends a fast ramp-up to 150 percent above FY 2020 levels over the next five years.

Box 1: An Innovation Agenda for Hydrogen & Fuel Cells Technologies

The *Energizing America* report co-authored by the Information Technology and Innovation Foundation (ITIF) and Columbia University's Center on Global Energy Policy offers several recommendations to accelerate innovation in hydrogen and fuel cells. Similarly, ITIF's March 2021 report "Building Bank Cleaner with Industrial Decarbonization Demonstration Projects" makes recommendations to DOE and Congress:

- Congress should ramp up investment in hydrogen RD&D by 150 percent over the next five years. This increase is needed to drive down costs of hydrogen production and realize its potential applications in hard-to-abate industrial and transportation sectors.[16]
- The Biden administration's infrastructure package should include $5 billion over five years for cost-shared demonstration projects that mitigate process and combustion emissions in heavy industries such as steel, cement, and chemicals by using clean hydrogen.[17]
- Congress should reauthorize HFTO and expand its mandate to encompass industrial applications, including thermal process heating, direct-reduction of iron for steel production, synthetic fuels, long-duration energy storage, electricity generation, and building heating. Congress should explicitly authorize demonstration projects in large-scale electrolyzers, steel production, and gas turbines.[18]
- HFTO and the DOE Office of Basic Energy Sciences (SC-BES) should coordinate to facilitate the hand-off of basic research—e.g., at the Joint Center for Artificial Photosynthesis—to the applied RD&D programs as promising zero-carbon-fuel production pathways mature. Additionally, the technology challenges identified in the applied programs should inform the basic research directions pursued by SC-BES.[19]

Hydrogen & Fuel Cells RD&D Subprograms

RD&D in the Hydrogen & Fuel Cells program is distributed across six subprograms:[20]

- **Fuel Cell Technologies** supports RD&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 Research and Development (R&D)** focuses on novel hydrogen production—including 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, and Analysis** performs research that provides a technical basis for informed decision-making for the program's R&D direction and prioritization.
- **Systems Development and Integration** focuses on advancing the technologies that allow for the integration of 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 2022 Budget Proposal[21]

The budget proposal seeks $197.5 million for the Hydrogen & Fuel Cells program, a 32 percent boost from FY 2021 enacted levels. Some highlights include:

- **A 40 percent increase in Fuel Cell Technologies,** including a shift from early-stage R&D to demonstration of hydrogen fuel cells in heavy or medium duty trucks as part of the SuperTruck funding opportunity.
- **An 11 percent increase in the Hydrogen Technologies,** including increased funding for manufacturing, development, and demonstration of electrolyzer systems and components and balance of system components.
- **A 59 percent increase in Systems Development & Integration,** with a $30 million increase in funding to integrate and demonstrate electrolyzers powered by renewable power sources and clean hydrogen as feedstock or direct reducing agent for ammonia and steel production.
- **No change in Data, Modeling & Analysis.**

Further Reading

- Varun Sivaram et al., *Energizing America: A Roadmap to Launch a National Energy Innovation Mission* (ITIF and Columbia University SIPA Center on Global Energy Policy, 2020), http://www2.itif.org/2020-energizing-america.pdf.
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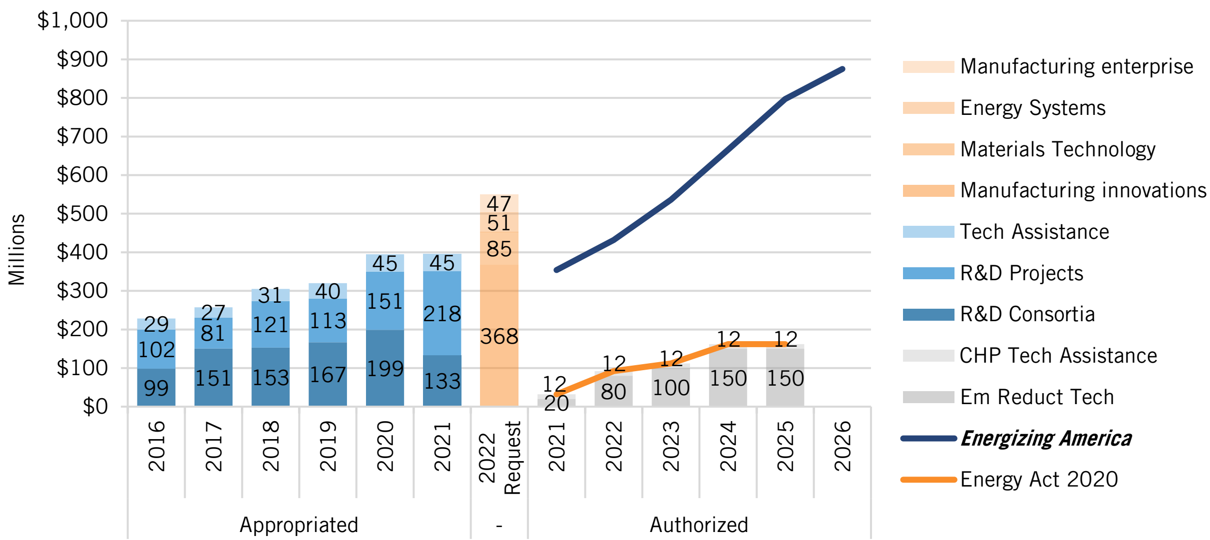
Federal Energy R&D: Advanced Manufacturing

BY COLIN CUNLIFF AND LINH NGUYEN | JUNE 2021

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, development, and demonstration (RD&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 RD&D through competitive funding opportunities designed to develop novel manufacturing technologies.[1]

Figure 1: *Energizing America* recommends ramping up funding for clean manufacturing RD&D by 150 percent by FY 2026. [2]



What's at Stake

The manufacturing sector accounts for 22 percent of direct U.S. greenhouse gas emissions—and 30 percent when indirect emissions from electricity generation are included. At the same time, U.S. manufacturing employs over 12 million people and plays an outsize role in the health of the U.S. economy because of its impact on trade and innovation and its large multiplier effect on other sectors. Despite its importance, advanced manufacturing accounts for just 6 percent of DOE's energy RD&D portfolio.[3]

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 already 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.[4]

The Clean Energy Manufacturing Initiative (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, sustainable manufacturing, and improving cybersecurity. The institutes were originally funded at $14 million per year for five years, with a requirement of at least a 50/50 cost-share from private sector partners. DOE adopted a five-year window for CEMI institutes to transition fully to non-federal funding sources; however, comparable programs in other countries—such as the Fraunhofer Institutes in Germany—receive core institutional funding from the national government on a permanent basis. The Information Technology and Innovation Foundation (ITIF) has previously recommended that DOE provide ongoing funding, contingent on continued industry participation, beyond the initial five-year window.[5]

While AMO has primarily focused on reducing the energy intensity of manufacturing, 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.[6] In the FY 2020 budget cycle, the Senate directed AMO to develop a series of sector-specific decarbonization roadmaps to guide RD&D activities across DOE.[7] While encouraging, such a refocusing should have been accompanied by a significant scale-up in funding, commensurate with the challenge of addressing industrial emissions.

The Energy Act of 2020 authorizes $12 million annually for FY 2021 to FY 2026 for DOE to carry out a technical assistance program that encourages the deployment of combined heat and power (CHP), waste heat to power, and efficient district energy through education and outreach.[8] Moreover, the bill includes the Clean Industrial Technology Act, which establishes a new Industrial Emissions Reduction Technology Development program within DOE. The program focuses on the development and evaluation of innovative emissions reduction technologies from non-power industrial sectors, including iron, steel, steel mill products, aluminum, cement, glass, pulp, paper, and industrial ceramics. The bill authorizes $20 million for FY 2021, $80 million for FY 2022, $100 million for FY 2023, $150 million for FY 2024, and $150 million for FY 2025 for DOE to carry out industrial decarbonization demonstration projects.[9] It does not specify the relationship between the new program and the rest of DOE's RD&D programs, and it is unclear whether the new program will be housed within AMO or be external to AMO. The Energy Act does not include authorized funding levels for other AMO programs.

Figure 1 shows historical DOE investment in advanced manufacturing technologies RD&D by subprogram, for FY 2016 through 2021, and the FY 2022 budget request. The orange line shows authorized funding levels from the Energy Act of 2020. The blue line shows recommended funding levels from the *Energizing America* report (see box 1). Because clean manufacturing makes up a disproportionately small share of the federal energy RD&D budget—the industrial sector accounts for 22 percent of direct U.S. greenhouse gas emissions but only 6 percent of DOE's portfolio—*Energizing America* recommends a fast ramp-up to 150 percent above FY 2020 levels over the next five years.

Box 1: An Innovation Agenda for Advanced Manufacturing Technologies

The *Energizing America* report co-authored by ITIF and Columbia University's Center on Global Energy Policy offers several recommendations to accelerate industrial decarbonization. Similarly, ITIF's March 2021 report "Building Back Cleaner With Industrial Decarbonization Demonstration Projects" makes recommendations to scale up clean manufacturing technologies in heavy industry. And ITIF's December 2018 report "Manufacturing USA at DOE: Supporting Energy Innovation" makes recommendations to DOE and Congress to maximize the effectiveness of DOE's clean energy manufacturing innovation institutes programs:

- The Biden administration's infrastructure package should include $5 billion over five years in cost-shared demonstration projects that seek to drastically reduce greenhouse gas emissions from heavy industries such as steel, cement, and chemicals.[10]
- Congress should ramp up investment in industrial decarbonization and clean manufacturing RD&D by 150 percent over the next five years. This increase is needed to rebalance the research portfolio and make up for historical underinvestment. The industrial sector accounts for 22 percent of direct U.S. greenhouse gas emissions (30 percent when emissions from electricity are distributed by end use), but accounts for only 6 percent of DOE's portfolio.
- Congress and DOE should provide opportunities for CEMI institutes to receive federal funding beyond the five-year window, and consider establishing a permanent support program.[11]
- DOE should establish additional CEMI institutes that focus on other high-priority advanced manufacturing technologies as identified in the Quadrennial Technology Review.[12]
- DOE should expand programs in carbon capture technologies to include industrial process applications such as steel and cement, as current programs focus on power plant applications.[13]
- AMO should expand research on uses of zero-carbon fuels and feedstocks (such as hydrogen) in the industrial sector to mitigate direct carbon dioxide emissions from chemical transformations and high-temperature heat.[14]

Advanced Manufacturing RD&D Subprograms

Unlike other DOE technology programs structured around technical focus areas, AMO subprograms are structured around modes of program implementation: individual research and development (R&D) projects, collaborative R&D consortia, and technology partnerships.[15]

- **R&D Projects** focuses 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** brings 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.[16]
- **Technical Assistance** helps small and medium-sized manufacturers improve their energy productivity and reduce waste and water use; demonstrates the viability of improved energy-management approaches; and promotes combined heat and power and waste heat to power technologies to improve efficiencies and lower energy costs.

Key Elements of the FY 2022 Budget Proposal[17]

The proposal seeks $550.5 million for the AMO, a 39 percent boost from FY 2021 enacted levels. Through FY 2021, AMO subprograms have been structured around modes of program implementation: individual R&D projects, collaborative R&D consortia, and technology partnerships. The FY 2022 budget presents a new subprogram structure across four technical areas to address industrial decarbonization and manufacturing innovation.

- **Materials** will focus on enabling domestic manufacturing of critical materials for energy technologies, including energy conversion materials, nanomaterials, and materials for extreme or harsh conditions, and developing advanced materials that reduce life-cycle carbon emissions through materials reuse and recycling. AMO will establish a new lab-industry consortium to validate critical materials technology innovation and solicit new projects on critical material needs.
- **Manufacturing Innovations** will focus on developing new manufacturing technologies that improve energy efficiency and reduce carbon emissions. The subprogram will fund the second year of the CEMI institute and launch two additional CEMI institutes. It will also support the Decarbonizing Industry Initiative through research and demonstration projects focused on zero-carbon production technologies, electrification, electrochemical manufacturing, enhanced drying, and direct air capture, and green hydrogen.
- **Energy Systems** will focus on RD&D for energy conversion, utilization, and storage technologies and innovative use of these technologies to improve production processes within industrial facilities. AMO will cut funding for fossil fuel-based district energy systems and increase funding for research focused on advance integrated high temperature electrolyzers and energy storage.

- **Manufacturing Enterprises** will provide technical assistance and workforce development for implementing energy and water efficiency projects and practices.

Further Reading

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About ITIF

The Information Technology and Innovation Foundation (ITIF) is an independent, nonprofit, nonpartisan research and educational institute focusing on the intersection of technological innovation and public policy. Recognized by its peers in the think tank community as the global center of excellence for science and technology policy, 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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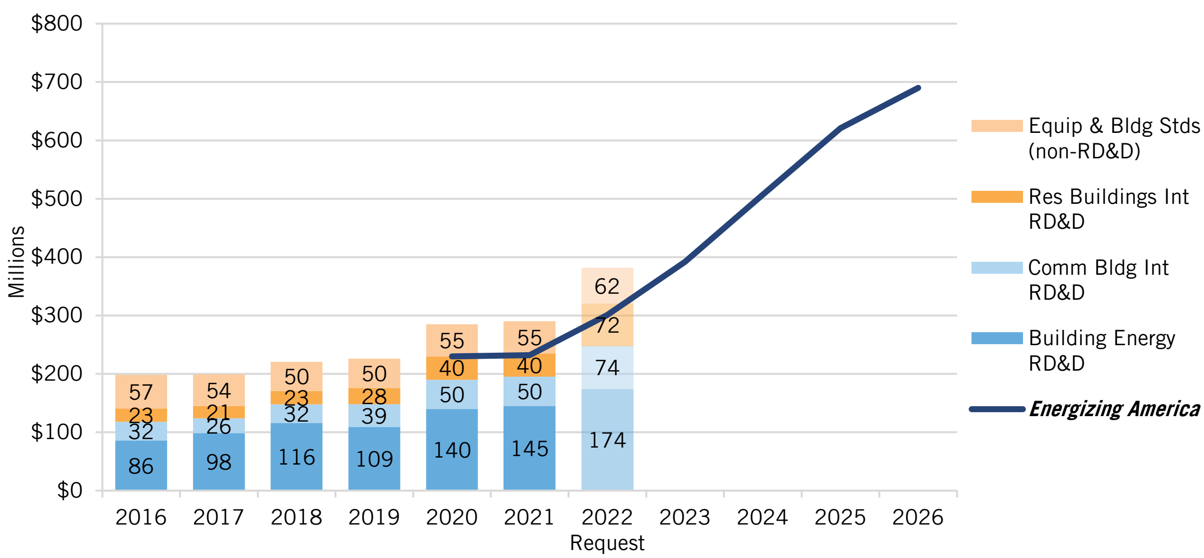
Federal Energy RD&D: Building Technologies

BY COLIN CUNLIFF AND LINH NGUYEN | JUNE 2021

The Department of Energy's (DOE) Building Technologies Office (BTO) invests in research, development, and demonstration (RD&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 both energy-efficient appliances or equipment and system and whole-building energy usage.[1]

Figure 1: *Energizing America* recommends ramping up funding for building technologies RD&D by 150 percent by FY 2026. [2]



What's at Stake

Residential and commercial buildings are the single largest energy-consuming sector in the U.S. economy, accounting for 72 percent of the nation's electricity use and 40 percent of its total energy demand.[3] As a result, Americans spend nearly $400 billion each year to power their homes, offices, schools, hospitals, and other buildings.[4] When all greenhouse gas emissions, including from electricity generation, are distributed by end-use sector, buildings account for the largest share of gross emissions at 32 percent, ahead of the industrial and transportation sectors.[5] Despite its prominence as an energy-consuming sector and leading source of emissions, the buildings sector accounts for only 4 percent of DOE's applied energy technology portfolio. The Information Technology and Innovation Foundation (ITIF) and other prominent organizations, including the International Energy Agency, have recommended that government energy RD&D programs increase focus on end-use innovations.[6]

The Building Technologies program has established the goal of reducing from 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.[7] 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 envelopes and windows (35 percent); appliances (30 percent); and sensors and controls (20 percent).[8] 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.[9]

BTO leads DOE's research in smart buildings, smart appliances, and grid-integrated efficient buildings (GEBs). As part of a new research initiative to develop GEBs, DOE is exploring artificial intelligence (AI) applications in whole building controls, sensors, modeling, and analytics, as well as applications in advanced lighting and HVAC systems.[10] In October 2020, BTO also launched a Connected Communities funding opportunity announcement, which will provide up to $65 million for communities to pilot new technologies that enable groups of buildings and distributed energy resources to connect and cooperate to optimize energy performance.[11]

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, 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 $10.7 billion, 1.76 quadrillion BTUs in energy savings, and 105 million tons of avoided carbon dioxide emissions since 2011, while partnerships with other federal agencies have resulted in over $12.3 billion in cumulative energy cost savings.[12]

The Energy Act of 2020 provides the first reauthorization of DOE's Building Technologies program in over a decade. The bill directs DOE to establish a Federal Smart Building Program to demonstrate the cost and benefits of smart buildings and implement associated technologies. It also establishes an RD&D program that targets innovation for building-to-grid integration, including low-cost, low-power, wireless sensors to monitor building energy load, forecast building energy need, and enable building-level energy control; advanced data management capabilities to enhance building and grid interoperability; and advanced energy management components such as control systems to enable energy efficiency and savings. Moreover, as part of the agency's Better Buildings Challenge, the bill requires DOE to demonstrate innovative policies and strategies for the transition to smart buildings in the public, institutional, and commercial buildings sectors.[13]

Figure 1 shows historical DOE investment in building technologies RD&D by subprogram, for fiscal years 2016 through 2021, and the FY 2022 budget request. The blue line shows recommended RD&D funding levels from the *Energizing America* report (see box 1). Recommended funding levels are for RD&D subprograms only and exclude the Equipment and Building Standards subprogram. Because buildings make up a disproportionately small share of the federal energy RD&D budget (32 percent of U.S. greenhouse gas emissions, when emissions from electricity generation are distributed according to use) *Energizing America* recommends a fast ramp-up to 150 percent above FY 2020 levels over the next five years.

Box 1: An Innovation Agenda for Building Technologies

The *Energizing America* report co-authored by ITIF and Columbia University's Center on Global Energy Policy offers several recommendations to accelerate innovation in building technologies. Similarly, ITIF's March 2021 report "How Congress and the Biden Administration Could Jumpstart Smart Cities with AI" makes recommendations to DOE and Congress on grid-integrated buildings and smart building technologies:

- Congress should ramp up investment in building technologies RD&D by 150 percent over the next five years. This increase is needed to rebalance the research portfolio and make up for historical underinvestment. The buildings sector accounts for 12 percent of direct U.S. greenhouse gas emissions, which jumps to 32 percent when emissions from electricity are distributed by end-use sector. But buildings make up just 6 percent of DOE's research portfolio.[14]
- Congress should increase investment in RD&D of AI for building energy applications, including DOE programs in advanced grid RD&D, grid-integrated efficient buildings, and energy systems integration.[15]
- DOE and the Environmental Protection Agency (EPA) should research alternatives to F-gas refrigerants with high global warming potential. DOE should also support the development of refrigerant-free air conditioning technologies such as solid-state cooling.[16]
- DOE should expand investment in advanced air flow, air sealing, ventilation controls, and high-performance windows to improve building energy efficiency.[17]
- DOE should invest in developing energy-efficient air conditioners that are suitable for hot or humid climates and collaborate with international partners such as India.[18]
- BTO should coordinate with the Geothermal Technologies Office to research geothermal heat pumps that enable buildings to exchange heat with the ground through connections with HVAC systems.[19]

Building Technologies RD&D Subprograms

BTO RD&D activities are divided among three main subprograms:[20]

- **Building Energy R&D (BERD)** sponsors research and development (R&D) in energy-efficient building technologies; buildings-to-grid; lighting; heating, ventilation, and air-conditioning & refrigeration; windows & envelopes; solid-state lighting; and building energy modeling.
- **Commercial Buildings Integration (CBI)** conducts RD&D and analytical studies of building systems (e.g., lighting, HVAC, envelopes, 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 RD&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 2022 Budget Proposal[21]

The budget proposal seeks $382 million for BTO RD&D activities, a 32 percent boost from FY 2021 enacted levels. Some highlights include:

- **A 48 percent increase in the Commercial Buildings Integration subprogram,** including funding for later-stage development and commercialization activities, such as the High Impact Technology Innovation Catalyst (HIT Catalyst) program which supports demonstration and validation of building systems optimization and advanced technology solutions and continued funding for the Better Buildings Initiative.
- **An 80 percent increase in the Residential Buildings Integration subprogram,** including expanded RD&D funding for Advanced Building Construction (ABC) technologies to meet the Administration's goal of building or retrofitting 1 million homes in four years; continued funding for the Solar Decathlon challenge to design and build new highly-efficient solar-powered homes; and technical assistance and partnerships to scale the use of high efficiency technologies such as heat pumps and low-emissivity windows.
- **A 13 percent increase in the Emerging Technologies (formerly Building Energy R&D) subprogram,** with increased funding for projects focused on advanced building energy management systems and grid interactive control technologies to reduce energy consumption and carbon emissions. The request also increases funding for research on lower global warming potential refrigerant technologies, especially for supermarket refrigeration application.

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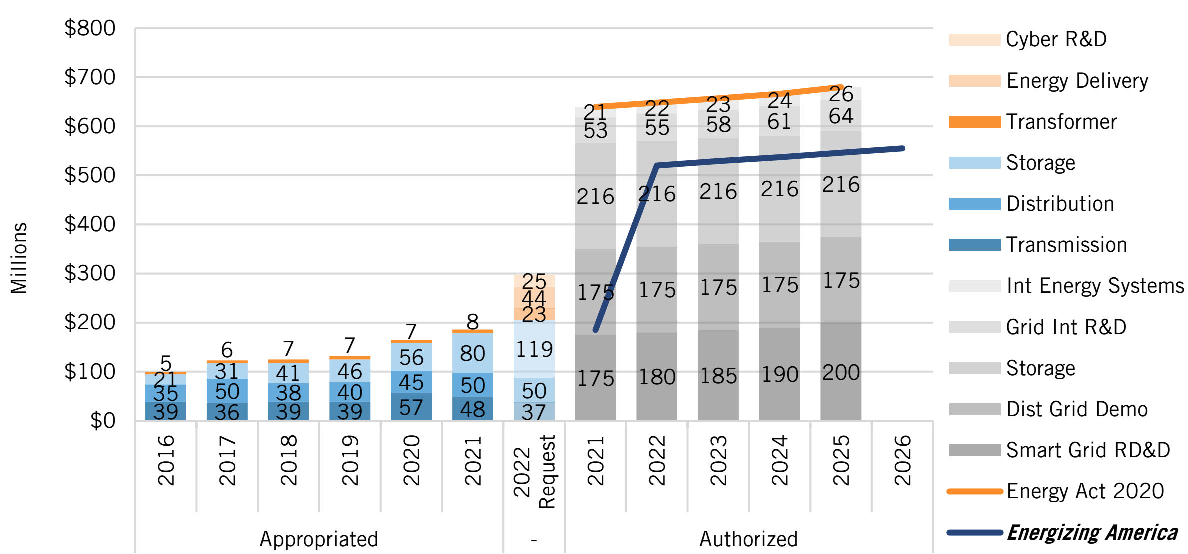
Federal Energy RD&D: Grid Modernization

BY COLIN CUNLIFF AND LINH NGUYEN | JUNE 2021

The grid modernization research, development, and demonstration (RD&D) programs in the Office of Electricity (OE) seek to accelerate discovery and innovation in electricity transmission, storage, and distribution technologies so that they incorporate greater levels of distributed and variable energy resources, provide enhanced connectivity between systems and devices, and improve reliability and resilience. OE aspires 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 the 2021 winter storm in Texas. The OE-funded RD&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 Energy Act of 2020 proposes new grid modernization RD&D programs, roughly in line with recommendations from *Energizing America*.[3]



What's at Stake

Electricity is fundamental to our daily lives, and also the economy. But the U.S. electricity system faces a number of critical challenges, even as the nation becomes more reliant on electric power: aging infrastructure that needs to be updated; increasing frequency of extreme weather events and billion-dollar disasters; greater proliferation of distributed energy resources, demand-side resources, and two-way power flows; digitization and integration of smart appliances and other connected devices that interact with the grid; and a changing generation profile marked by greater reliance on variable generation.[4] At the same time, the grid must rapidly decarbonize and expand to enable the decarbonization of other key sectors.[5] Grid modernization is key to addressing these challenges and enabling the power system of the future.[6]

In collaboration with the utility industry, the Department of Energy (DOE) in 2015 established the Grid Modernization Initiative to coordinate research and development (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.[7] For its part, DOE set targets and performance measures in reliability and resilience, as well as cost and performance targets for new grid storage technologies, to pursue by 2020.[8] However, DOE has not updated this roadmap since 2015, despite congressional pressure to do so. In March 2021, the National Academies of Sciences, Engineering, and Medicine (NASEM) released *The Future of Electric Power in the United States,* which develops recommendations to DOE, Congress, and state and utility stakeholders to address critical needs for grid modernization.[9]

As electricity from variable wind and solar takes greater shares in the U.S. power grid, the need for flexible energy storage technologies increases. Energy storage can decrease grid variability and help balance electricity supply and demand during periods when the sun is not shining or the wind is not blowing. A report by the Information Technology and Innovation Foundation (ITIF) finds that low-cost, long-duration energy storage technologies at grid scale are needed if renewables are to fully displace carbon-emitting fossil fuels.[10] DOE has been ramping up its work in grid-scale energy storage. On March 10, 2021, DOE announced the construction of the 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.[11] The Grid Storage Launchpad will also support DOE's Energy Storage Grand Challenge, a program to accelerate the development of domestically manufactured energy storage technologies.[12]

Smart grid technologies—e.g., technologies that allow for enhanced sensing and control of grid elements, enable two-way communication between the grid and other infrastructures, use more powerful computer processing, and have finer control systems—can support renewables integration and enable increased energy efficiency, reliability, and security.[13] While DOE's Grid Modernization Initiative roadmap identifies several smart-grid-related artificial intelligence applications, an updated roadmap that includes a smart grid RD&D agenda is needed.

There are currently no active federal programs that support the deployment of smart grid infrastructure. The American Recovery and Reinvestment Act of 2009 included $3.4 billion for the Smart Grid Investment Grant (SGIG) program, which provided funding for the deployment of smart meters, distribution automation systems, advanced sensors known as Phasor Measurement Units (PMUs), and customer systems such as smart applications and building energy management systems.[14] Smart meters, which track and communicate real-time energy usage, have been critical to expanding participation in demand response programs and giving utility customers greater insight and control over their energy consumption.[15] While the first SGIG program nearly doubled the number of smart meters installed, nearly half of U.S. customers still lack smart meters.[16] No similar programs have been established since SGIG ended.

The Energy Act of 2020 includes the Grid Modernization R&D Act, which establishes a smart grid regional demonstration initiative; a program on smart grid modeling, sensing, visualization, architecture development, and advanced operation and control; a program to enhance grid resilience and strengthen emergency response; a program to develop hybrid energy systems; a program for renewable energy, electric vehicles, and buildings integration onto the electric grid; and new programs for technology demonstrations on the distribution grid, micro-grid, and integrated micro-grid systems. It provides separate authorizations for each program for FY 2021 through FY 2025, as depicted in figure 1.[17] The bill also includes the Better Energy Storage Technology (BEST) Act, which authorizes the creation of a cross-cutting RD&D program within DOE for energy storage technologies across multiple timescales—from hourly and sub-hourly to seasonal. DOE is required to carry out three energy storage demonstration projects, including at least one project for storage technologies that have the capacity to discharge energy for 10 to 100 hours at minimum, or have the capability to address seasonal variations in supply and demand. Moreover, the act establishes a joint long-term demonstration initiative with the Department of Defense (DOD), and an energy storage materials recycling R&D program.[18]

Figure 1 shows historical DOE investment in grid modernization RD&D by subprogram for FY 2016 through FY 2021. The blue line shows recommended funding levels from the *Energizing America* report (see box 1). The orange line shows authorized funding levels from the Energy Act of 2020, which are roughly in line with *Energizing America* recommendations.

Box 1: An Innovation Agenda for Grid Modernization

The *Energizing America* report coauthored by the Information Technology and Innovation Foundation (ITIF) and Columbia University's Center on Global Energy Policy offers several recommendations for grid modernization. Similarly, ITIF's March 2021 report "How Congress and the Biden Administration Could Jumpstart Smart Cities with AI" and November 2018 report "Making 'Beyond Lithium' a Reality: Fostering Innovation in Long-Duration Grid Storage" make recommendations to DOE and Congress to accelerate the adoption of smart grid technologies:

- Congress should appropriate full funding for the grid modernization and energy storage R&D and demonstration projects authorized in the Energy Act of 2020. [19]
- Congress should establish a DOE research program on recycling lithium, cobalt, and other materials used in energy storage in order to reduce supply chain risks and dependence on imports. DOE recently launched a new battery-critical minerals recovery and recycling research initiative under its existing authorities; and Congress should pass authorizing legislation to provide greater direction and long-term budget certainty for the new program.
- Congress should revive the SGIG program to support the deployment of advanced metering infrastructure and other smart grid investments.[20]
- Congress should increase funding for RD&D in high-voltage direct current (HVDC) transmission, including advancing power electronics and converter and conductor technologies, and demonstrating meshed networks of HVDC lines.[21]

- DOE should update its Grid Modernization research plan to include artificial intelligence applications identified in the Grid Modernization Multi-Year Program Plan. DOE has not updated its research plan since 2015, leaving the smart grid research agenda uncoordinated with different technology programs.[22]
- DOE and DOD should launch a joint storage demonstration program to leverage and coordinate research in high-energy-density storage media.[23]

Grid Modernization RD&D Subprograms

Grid modernization RD&D is made up of four main subprograms:[24]

- **Transmission Reliability and Resilience** focuses on ensuring the reliability and resilience of the electric grid through RD&D on measurement and control of the electrical system, and risk assessments to address challenges across integrated energy systems.
- **Resilient Distribution Systems** pursues strategic RD&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** supports modernization, hardening, and resilience of grid components, including transformers, power lines, and substation equipment.

Key Elements of the FY 2022 Budget Proposal[25]

The budget proposal seeks $327 million for grid modernization RD&D activities, a 54 percent boost from FY 2021 enacted levels. Some highlights include:

- **A new $25 million Cyber R&D subprogram,** which focuses specifically on cybersecurity R&D for electricity delivery systems. The Office of Cybersecurity, Energy Security, and Emergency Response retains the lead responsibility for crosscutting cybersecurity issues that go beyond electricity delivery systems.
- **No change to the Resilient Distribution Systems subprogram,** with continued funding for distribution sensors R&D activities; support for a Balance-Centric Grid Funding Opportunity Announcement targeting DERs and storage; funding for competitively selected projects that develop and demonstrate innovative technologies to enhance distribution systems resilience to physical hazards and support decarbonization goals; no new funding for the National Test Bed Laboratory for Coordinated Management of Microgrids and Networked Distributed Energy Resources (COMMANDER) as this was fully funded in FY 2021; and continued funding for the Situational Awareness Network (SAN) activities.

- **A 49 percent increase in the Energy Storage subprogram,** with $24 million to complete funding for the construction and commissioning of the Grid Storage Launchpad facility at PNNL. Funding for other RD&D activities within this subprogram would be increased by $15 million, with a focus on demonstration of next-generation storage technologies (battery and non-battery) for grid applications and the validation and demonstration of long duration (6+ hours) energy storage technologies.
- **A 23 percent decrease in Transmission Reliability and Resilience subprogram,** primarily due to the completion of funding for the North American Energy Resilience Model (NAERM) Phase II development. Funding will now focus on sensor research, data analytics, and software tool development to improve transmission system flexibility and reliability. Funding will also support a new university-based Engineering Research Center, which would focus on fundamental research on the electric power system.
- **A 2 percent increase in Transformer Resilience and Advanced Components,** including an additional $15 million to expand R&D on solid-state power substations (SSPS)—which has 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.
- **A new $44 million Energy Delivery Grid Operations Technology subprogram,** which focuses on bringing technologies from R&D to operation. This subprogram would support the operation and maintenance of the NAERM platform, which has been fully funded by the Transmission Reliability and Resilience subprogram and is ready for operation. It also provides operational support and expansion of SAN transitions from the Resilient Distribution subprogram.

Further Reading

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Acknowledgments

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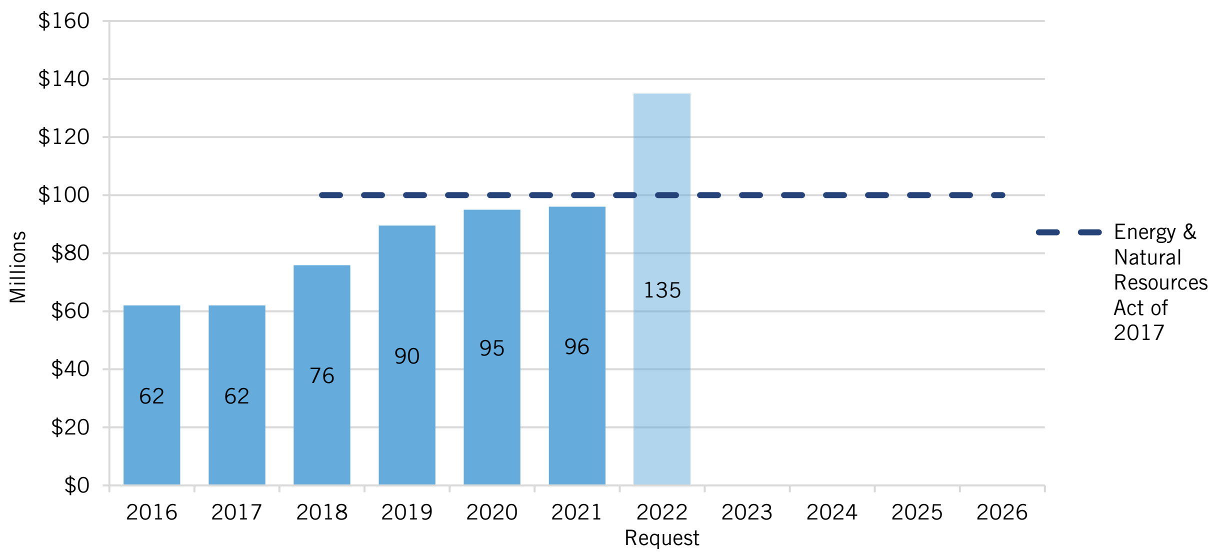
Federal Energy RD&D: Cybersecurity for Energy Systems

BY COLIN CUNLIFF AND LINH NGUYEN | JUNE 2021

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 both strengthen the cybersecurity of critical energy infrastructure against current and future threats and mitigate vulnerabilities.[1]

Figure 1: Historical funding for CEDS research, development, and demonstration (RD&D)[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 to disrupt U.S. grid operations.[5] The COVID-19 pandemic, which forced employees across the energy industry to work remotely, has created a unique opportunity for cybercriminals and led to an unprecedented rise in cyberthreats to critical energy infrastructure. The major cyber hack on IT management software company SolarWinds in December 2020, which compromised major federal agencies like the Federal Energy Regulatory Commission and power utilities such as the New York Power Authority, underscores the dangers of cyberthreats to the grid and the need for action.[6]

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.[7] 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.[8] 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.[9] 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 RD&D is needed to work with industry partners to create cyberthreat detection, prevention, and mitigation tools for energy delivery systems.

The Fixing America's Surface Transportation Act of 2015 provides DOE the authority to protect and restore the power grid during a grid security emergency, including grid cyberattacks. The act directs DOE to work with DHS, in collaboration with infrastructure owners and operators, to identify vulnerabilities, improve emergency preparedness, and manage cyber incidents.[10] The Senate Energy and Natural Resources Act of 2017 (S. 1460) establishes a program for energy sector cybersecurity RD&D and authorizes $65 million annually for FY 2018 through FY 2026 for the program to be carried out by DOE. The bill also authorizes $15 million annually for an energy sector component testing for cyber resilience program, $10 million annually for an energy sector operational support for cyber resilience program, and $10 million annually for an advanced energy security program for FY 2018 through FY 2026.[11]

Figure 1 shows historical DOE investment in CEDS RD&D for FY 2016 through FY 2021 and the FY 2022 budget request. The dashed blue line shows authorized funding levels from the Senate Energy and Natural Resources Act (S. 1460), which was introduced in 2017 but was unable to pass the Senate and ultimately did not become law.

Cybersecurity RD&D Activities

In FY 2021, CEDS focused on these key RD&D activities:[12]

- **Cyber Analytic Tools and Techniques™ 2.0 (CATT™ 2.0)** provide situational awareness and actionable information to support discovery and mitigation of cyberthreats 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™)** support 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 both to facilitate the timely bidirectional sharing of unclassified and classified threat information, and to 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 2022 Budget Proposal[13]

The Cybersecurity, Energy Security, and Emergency Response (CESER) office houses the Risk Management Technology and Tools (RMT) program, formerly the Cybersecurity for Energy Delivery Systems (CEDS) R&D program. CESER also houses the Infrastructure Security and Energy Restoration (ISER), an energy-sector emergency-support function that does not include R&D activities. Elements of RMT's proposed budget include:

- Continued funding for existing cybersecurity projects, including CyOTE™ and C2M2.
- Increase in funding for the Cybersecurity Testing for Industrial Control Systems (CyTRICS), which focuses on cyber supply chain vulnerability testing and component design and manufacturing improvements. Funding will support two additional testing labs (NREL and ORNL) and scale up cyber supply chain vulnerability testing for the digital components of renewables and distributed energy resources.
- Funding for RD&D of next-generation cyber information sharing tools and technologies to enhance the ability to detect cyberthreats.

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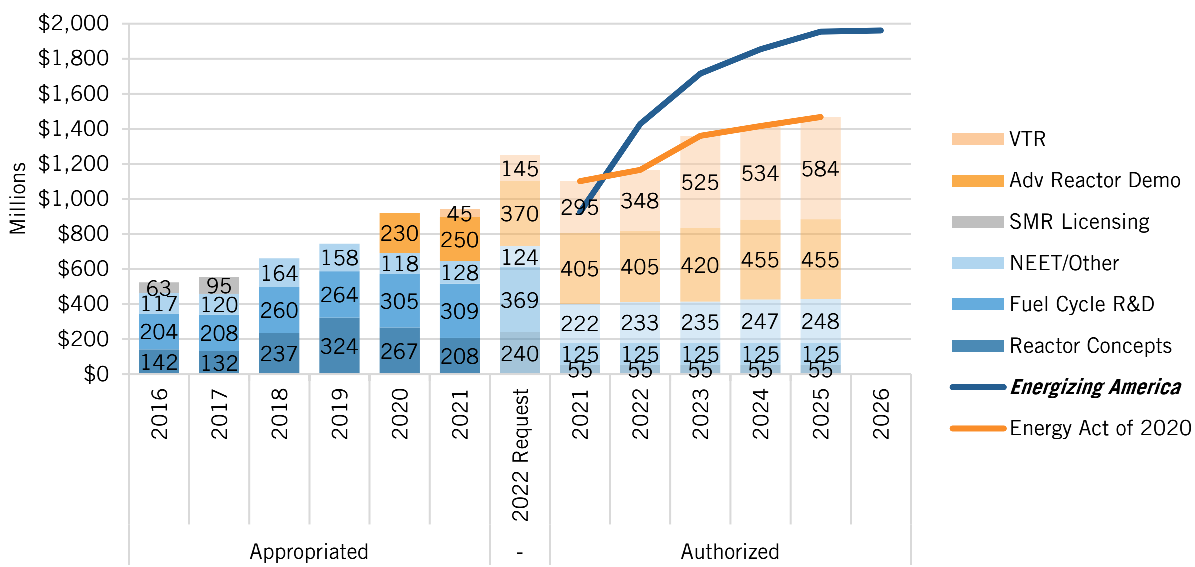
Federal Energy RD&D: Nuclear Energy

BY COLIN CUNLIFF AND LINH NGUYEN | JUNE 2021

Nuclear power accounts for 19 percent of the electricity generated in the United States, and 53 percent of all carbon-free electricity—more than hydropower, geothermal, wind, and solar combined.[1] Despite this success, the existing nuclear fleet is being challenged by low-cost natural gas and renewables, while 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, development, and demonstration (RD&D) on the technical challenges of maintaining the existing reactor fleet and pursues the development of a robust pipeline of advanced reactor designs and supply-chain capabilities.[3]

Figure 1: *Energizing America* recommends roughly doubling the funding for nuclear RD&D by FY 2026.[4]



What's at Stake

With 94 commercial reactors, the United States has the largest nuclear energy industry in the world. Yet, even though the United States took an early lead in this field in the 1950s and 1960s, its position has stagnated since then. Only two reactors have joined the fleet in the last 25 years. The rising costs of new nuclear plants combined with a wave of recent and planned retirements of existing plants has led some analysts to refer to nuclear power as "the vanishing low-carbon wedge."[5]

Technological innovation might address many of the challenges the current generation of nuclear power plants faces. 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 research and development (R&D) in advanced reactors since the late 1990s, and so far, no advanced reactor concepts have progressed to full-scale demonstration, let alone commercialization.[6] A recent analysis of DOE's nuclear budget going back two decades to 1998 finds shifting priorities, inconsistent funding from Congress, and a focus on incumbent technologies have resulted in few advances. And even if the program had been well designed, federal investment has been insufficient to demonstrate a single non-light-water advanced reactor technology.[7]

Recent actions in Congress and DOE aim to jump-start innovation in advanced nuclear technologies. In 2016, DOE launched the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative to help U.S. companies access experimental and computational capabilities at the national labs and other research facilities.[8] Congress passed the Nuclear Energy Innovation Capabilities Act (NEICA) in September 2018 to facilitate private-sector innovation in advanced reactor technologies. The Act authorized the National Reactor Innovation Center, which provides resources for testing, demonstration, and performance assessment to private sector technology developers.[9]

NEICA also authorized DOE to assess the need for a Versatile Test Reactor (VTR) user facility to enable testing in fast-neutron environments. Many advanced reactor designs are fast reactors that do not use a moderator to slow down neutrons. Development of these reactor concepts will require testing of materials and fuel designs in a fast-neutron environment; however, the United States currently has no fast-neutron research facilities that would enable developers to test their designs. In contrast, Russia has two operating commercial-scale fast reactors, and China launched a pilot-scale fast reactor for research and testing in 2011. The VTR would enable U.S. companies developing fast-reactor technologies to test them in domestic facilities rather than using the Bor-60 reactor in the Russian Federation.[10]

In FY 2019, the administration proposed a new R&D subprogram focused on advanced (non-light-water) Small Modular Reactors (SMRs), which Congress funded at $100 million.[11] And in the FY 2020 budget cycle, Congress established a new Advanced Reactor Demonstration Program to build and demonstrate two advanced reactor designs by the mid-2020s.[12] In October 2020, DOE funded its first awards to TerraPower LLC (Bellevue, WA) and X-energy (Rockville, MD) of $80 million each in initial funding to build two advanced reactors that are to be operational within seven years.[13] In December 2020, DOE selected five additional teams for "Risk Reduction for Future Demonstration" awards, which are intended to improve technology readiness and prepare those teams for future demonstrations in 10–14 years.[14]

The Energy Act of 2020 builds on the success of NEICA and provides the first reauthorization of DOE's Nuclear Energy program in over a decade. Notably, the act reauthorizes DOE's advanced reactor demonstration program, with $405 million for FY 2021, $405 million for FY 2022, $420 million for FY 2023, $455 million for FY 2024, and $455 million for FY 2025. It also authorizes $295 million for FY 2021, $348 million for FY 2022, $525 million for FY 2023, $534 million for FY 2024, and $584 million for FY 2025 for the VTR. The act reauthorizes reactor concepts RD&D, nuclear integrated energy systems RD&D, fuel cycle RD&D, nuclear integrated energy systems RD&D, and advanced reactor technologies R&D, and supports a radiological facilities management program and nuclear energy university program.[15]

Figure 1 shows historical DOE investment in nuclear energy RD&D by subprogram, for FY 2016 through FY 2021, the FY 2022 budget request. The orange line shows authorized funding levels from the Energy Act of 2020. The blue line shows recommended funding levels from the *Energizing America* report, which envisions a ramp-up in funding of 100 percent over the next five years (see box 1).

Box 1: An Innovation Agenda for Nuclear Energy

The *Energizing America* report coauthored by the Information Technology and Innovation Foundation (ITIF) and Columbia University's Center of Global Energy Policy offers several recommendations for DOE and Congress to drive nuclear energy innovation. Similarly, ITIF's 2018 report "An Innovation Agenda for Deep Decarbonization: Bridging Gaps in the Federal Energy RD&D Portfolio" makes recommendations to DOE and Congress to maximize the effectiveness of DOE's nuclear energy programs:

- Congress should follow through on its early support for the VTR, and commit to its construction to enable testing of materials and fuel designs in a fast-neutron environment, with a goal of making domestic fast-neutron testing capabilities available by 2026.[16]
- Congress should provide sufficient, stable multiyear funding for DOE to demonstrate at least two advanced reactor technologies by 2030.[17]
- DOE and the Department of Defense should partner to develop advanced microreactors. Fixed installations in remote areas are an ideal early market for stationary microreactors, which have the potential to supply reliable energy while reducing vulnerabilities associated with the fuel supply chain.[18]
- DOE should expand RD&D into other applications for nuclear energy, including desalination, industrial process heating, hydrogen and ammonia production, and other industrial applications.[19]

Nuclear Energy RD&D Subprograms

In FY 2021, NE has conducted RD&D in the following subprograms:[20]

- **Reactor Concepts RD&D** 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 five to seven 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 2022 Budget Proposal[21]

The budget proposal seeks $1,850.50 million for NE RD&D activities, a 23 percent boost from FY 2021 enacted levels. Some highlights include:

- **A 222 percent increase for VTR,** a user facility that will enable testing of materials and fuel designs common to many advanced, non-light-water-reactor designs.
- **A 48 percent increase for the Advanced Reactors Demonstration Program,** including increased funding for two advanced reactor demonstration projects; a $10 million increase in funding for risk reduction for future demonstrations; a $25 million increase for the National Reactor Innovation Center; and continued funding for regulatory development and advanced reactor safeguards research.
- **A 15 percent increase in Reactor Concepts R&D,** including advanced small modular reactor R&D; a $13 million increase for light-water reactor sustainability R&D; and a $19 million boost to advanced reactor technologies development.
- **A 19 percent increase in Fuel Cycle R&D,** including increased 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 for TRISO fuel would remain unchanged.
- **A 1 percent increase in Nuclear Energy Enabling Technologies,** including a $19 million increase for crosscutting technology development; a $12 million increase for nuclear science user facilities; no change in funding for the joint modeling and simulation program; and discontinued funding for the Transformational Challenge Reactor program.
- **Elimination of the STEP and nuclear workforce development programs.**

Further Reading

- Varun Sivaram et al., *Energizing America: A Roadmap to Launch a National Energy Innovation Mission* (ITIF and Columbia University SIPA Center on Global Energy Policy, 2020), http://www2.itif.org/2020-energizing-america.pdf.
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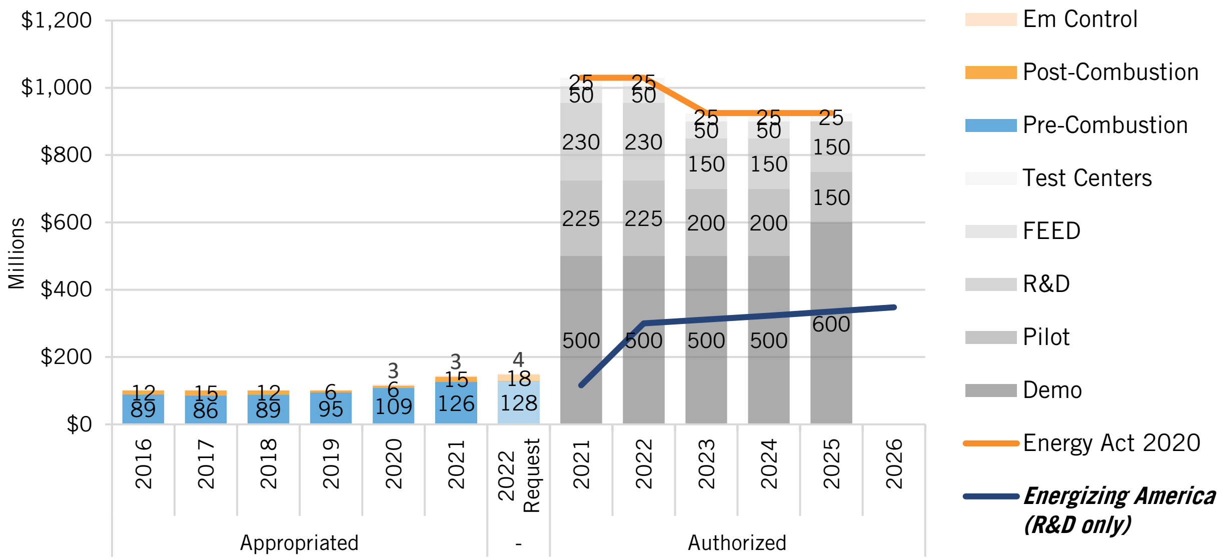
Federal Energy RD&D: Carbon Capture

BY COLIN CUNLIFF AND LINH NGUYEN | JUNE 2021

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 will also likely be needed to decarbonize many industrial processes—such as the production of ethanol, fertilizers, plastics, cement, and steel—for which low-carbon alternatives are not currently available.[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 was largely limited to coal in the past. The Energy Act of 2020 provides a much-needed expansion of carbon capture RD&D to other sources of emissions and prioritizes demonstration projects in order to address the technical challenges unique to each type of facility.

Figure 1: The Energy Act of 2020 provides a significant reorganization of carbon capture activities at DOE.[3]



What's at Stake

CCUS technologies prevent greenhouse gases from power plants and industrial facilities from reaching the atmosphere. The IPCC has found that CCUS is essential to achieving net-zero emissions: The majority of IPCC pathways consistent with 1.5°C of warming project the use of carbon capture and storage on the order of 350 million–1,200 million metric tons of carbon dioxide (MMt CO_2) over the 21st century.[4] The National Academies of Sciences, Engineering, and Medicine (NASEM) found that carbon capture and storage in the United States should grow to ~50–75 MMt CO_2/yr by 2030 (and as much as 250 MMt CO_2/yr by 2035) in order to be consistent with a net-zero emissions by 2050 pathway.[5]

CCUS may be on the cusp of significant new buildouts and cost reductions. DOE's Industrial Carbon Capture and Storage (ICCS) program successfully launched CCUS demonstration projects at the Port Arthur fertilizer facility in 2013, and the Archer Daniels Midland ethanol plant in

2017.[6] The Petra Nova coal power plant began capturing its carbon emissions in 2017 at a cost of about $60 per ton. (Although the plant recently closed due to declining revenues as a result of the COVID-19 pandemic, it was successful in facilitating learning that is projected to lead to 30 percent cost reduction for similar second-of-a-kind projects.[7]) 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 2022 to commercially deploy a 300-megawatt project using a supercritical CO_2 cycle.[8] 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.[9] And in February 2018, Congress expanded and extended the 45Q tax credit to incentivize greater utilization and storage of captured CO_2.[10]

However, costs must continue to decline, and infrastructure barriers (e.g., availability of CO_2 pipelines and storage infrastructure) must be addressed before CCUS will be viable for full-scale deployment. Several demonstration projects that were designated for federal support under the 2009 Recovery Act were never completed due to cost, scheduling, and other barriers.[11] 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.[12]

DOE's carbon capture program has primarily focused on coal-fired power plants, to the exclusion of natural gas power plants and other industrial sources. The ICCS program, which has 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.[13] This focus leaves the unique challenges of integrating and optimizing carbon capture with other sources of emissions unsolved. The Information Technology and Innovation Foundation (ITIF) recommends DOE establish new carbon capture programs for natural gas power plants and industrial facilities (see box 1).[14] ITIF also calls for the federal government to invest in a robust portfolio of demonstration projects, which would include major investments in CCUS.[15] 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.[16]

DOE has set the 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.[17] Additionally, DOE has sought to establish international leadership in CCUS technologies through its participation in the Clean Energy Ministerial and Mission Innovation.[18]

The Energy Act of 2020 incorporates many of the recommendations in *Energizing America*, and entails a significant restructuring and expansion of the program. The bill expands research and development (R&D) activities to include power plants and manufacturing and industrial facilities that use coal or natural gas. The bill also creates a new program to conduct large-scale pilot projects at a scale "beyond laboratory development and bench scale testing, but not yet advanced to the point of being tested under real operational conditions at commercial scale."[19] The bill directs DOE to begin six commercial demonstrations of carbon capture by 2025—two each from coal power plants, natural gas power plants, and industrial facilities—and authorizes funding to conduct front-end engineering design (FEED) studies to support the demonstration projects. Finally, the bill directs DOE to establish one or more Carbon Capture Test Centers, to support large-scale pilot and demonstration projects and test carbon capture technologies.[20]

Figure 1 shows historical DOE investment in carbon capture R&D by subprogram, for FY 2016 through 2021, and the FY 2022 budget request. (Appropriations by subprogram were unspecified for FY 2021, and the top-line number only is shown for that year.) The orange line shows total authorized funding levels in the Energy Act of 2020 for FY 2021 through 2025, across all carbon capture activities. Authorizations across the five new subprograms—carbon capture R&D, large-scale pilots, demonstration projects, FEED studies, and test centers—are shown as transparent bars. The blue line shows recommended R&D (only) funding levels from the *Energizing America* report (see box 1). *Energizing America* also recommends separate funding for large demonstration projects (not shown in figure 1), not broken down across technology or DOE program office.

Box 1: An Innovation Agenda for Carbon Capture

The *Energizing America* report coauthored by the Information Technology and Innovation Foundation (ITIF) and Columbia University's Center on Global Energy Policy offers several recommendations to accelerate carbon capture innovation.[21] ITIF's recent "Build Back Cleaner" report recommends creating a portfolio of carbon capture demonstration projects at industrial facilities such as for cement and steel manufacturing:[22]

- Congress should fully fund the Energy Act of 2020 authorization levels and continue to support the expansion of carbon capture R&D to include natural gas power plants and industrial facilities.

- Congress should provide full funding for technology scale-up activities through large-scale pilot and demonstration projects, FEED studies, and test centers. Congress should pay special attention to industrial carbon capture demonstration projects, including steel and cement manufacturing, wherein other countries have an early lead but where investments now could help the United States reclaim leadership in carbon capture technologies.[23]

- Congress and DOE should address CO_2 infrastructure and regulatory barriers that deter investment in carbon capture. DOE should work with the Department of Transportation, U.S. Geological Survey, and other agencies to plan and assess the requirements for a national CO_2 trunk pipeline network, characterize geologic storage reservoirs, and establish permitting rules.[24]

- Congress should extend the 45Q tax credit for CCUS, making the project fully refundable for projects that commence construction prior to 2022, and raising the credit to $70 per metric ton of CO_2 less the explicit carbon price established.[25]

- DOE should rename the Office of Fossil Energy as the Office of Carbon Management, refocus carbon-reduction and climate-mitigation activities and expand carbon capture research to applications in both the industrial and electricity sectors. This new office should coordinate with other DOE offices with complementary missions (e.g., Advanced Manufacturing Office (AMO) for industrial decarbonization and Bioenergy Technologies Office for bioenergy with carbon capture and storage (CCS)).

Carbon Capture RD&D Activities

RD&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.[26]

- **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 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.[27]

Key Elements of the FY 2022 Budget Proposal[28]

The budget proposal seeks $150 million for carbon capture RD&D activities, a 19 percent boost from FY 2021 enacted levels. Some highlights include:

- **An 18 percent increase in Post-Combustion Capture Systems,** including continued support for transformational small-scale and bench-scale carbon capture tests on flue gases from coal and natural gas; continued support for transformational pilot-scale carbon capture projects for industrial CO_2; increased funding to support ten carbon capture FEED studies for industrial and natural gas sources of CO_2; and funding to support the operation of the National Carbon Capture Center (NCCC) test facility.
- **A 20 percent increase in Pre-Combustion Capture Systems,** including increased funding to support carbon capture development and gasification design and component testing for clean hydrogen production.

Further Reading

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About ITIF

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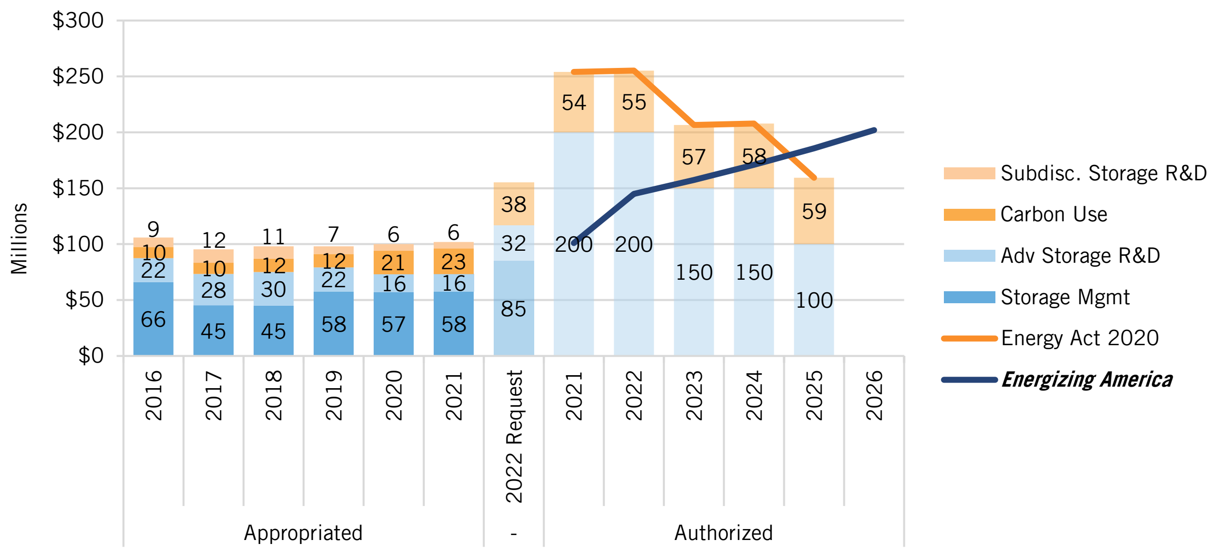
Federal Energy RD&D: Carbon Storage and Utilization

BY COLIN CUNLIFF AND LINH NGUYEN | JUNE 2021

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 for use in valuable products, such as chemicals, fuels, and building materials.

Figure 1: The Energy Act of 2020 authorizes a 150 percent increase in carbon storage and use in FY 2022.[2]



What's at Stake

Limiting global climate change to less than 2°C of warming may require between 20 billion and 60 billion tons of CO_2 to be captured and sequestered every year by the end of the century.[3] If so, carbon management will become one of the world's largest industries, equivalent in scale to food production (~15 billion tons), construction materials (>60 billion tons), and fossil fuel production (~20 billion tons).[4]

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.[5] 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 already been initially characterized, detailed site-specific work is required to confirm their potential. Research and development (R&D) are 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 1 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.[6] In 2018, as part of its Carbon Storage Assurance Facility Enterprise (CarbonSAFE) initiative, DOE selected three additional cost-shared research, development, and demonstration (RD&D) projects to identify sites that could store more than 50 million metric tons of CO_2.[7] This effort must be expanded. The National Academies of Sciences, Engineering, and Medicine (NASEM) recommends that DOE work with the Department of Interior and U.S. Geological Survey to "[c]haracterize sustained CO_2 injection rates that can be achieved across each of the major CO_2 sequestration basins and identify by 2030 high injection rate locations suitable for injection of approximately 250 million metric tons of CO_2 per year."[8]

Carbon utilization—turning CO_2 from waste into a product of value—provides another option for managing CO_2 and may be a glide path to incenting greater carbon capture. Most potential uses for captured carbon, such as carbon nanotubes and synthetic hydrocarbon fuels, are far from commercialized and require further RD&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 RD&D that needs to be identified by the study.[9]

The vast majority of captured carbon would ultimately need to be sequestered in geologic reservoirs. Even if carbon use expands substantially, potential markets to absorb CO_2 will be much smaller than the total carbon capture, utilization, and sequestration (CCUS) anticipated in a net-zero emissions world. For example, if CO_2 were used as the source of all carbon in the global annual production of plastics (311 million metric tons per year in 2014), it would consume about 0.8 gigatons of CO_2 per year, far less than 10 percent of the anticipated total previously referenced.[10]

The Energy Act of 2020 provides the first reauthorization of DOE's carbon use and storage program in over a decade. The bill directs DOE to establish a large-scale carbon sequestration demonstration program and requires DOE to produce a roadmap for carbon storage RD&D activities through 2025 to reduce economic and policy barriers to commercial carbon storage.[11] The bill also expands DOE's carbon utilization RD&D program and directs DOE to establish a two-year demonstration program in each of the major coal-producing regions to accelerate commercial deployment of coal-carbon products—such as carbon fiber derived from coal—that result in no significant emissions of CO_2 or other pollutants. The bill directs DOE to establish a national Carbon Utilization Research Center to support early-stage RD&D activities to convert CO_2 into valuable products and commodities.[12]

Figure 1 shows historical DOE investment in carbon utilization and storage activities by subprogram, for FY 2016 through 2021, and the FY 2022 budget request. (Appropriations for carbon storage by subprogram were unspecified for FY 2021, and the topline number only is shown.) The orange line shows total authorized funding levels in the Energy Act of 2020 for FY

2021 through 2025, across all carbon storage and use activities. Authorizations across carbon storage and use are shown as light orange and blue bars. The blue line shows recommended R&D (only) funding levels from the *Energizing America* report (see box 1).

Box 1: An Innovation Agenda for Carbon Storage and Use

The *Energizing America* report coauthored by the Information Technology and Innovation Foundation (ITIF) and Columbia University's Center on Global Energy Policy offers several recommendations to accelerate carbon storage and use innovation.[13]

- DOE should identify the funding levels needed to address the recommendations of the National Academies of Sciences, Engineering, and Medicine's (NASEM) roadmap for advancing CO_2 utilization technologies. Congress should provide sufficient funding to match the RD&D needs.[14]
- DOE should increase the ambition of its current carbon storage goal of 50 million metric tons of storage capacity characterized by 2026 and adopt the National Academies target of 250 million metric tons by 2030. DOE should develop a roadmap and funding levels to meet the new target, and Congress should provide sufficient levels of funding .[15]
- Congress and DOE should address CO_2 infrastructure and regulatory barriers that deter investment in carbon capture. DOE should work with the Department of Transportation, U.S. Geological Survey, and other agencies to plan and assess the requirements for a national CO_2 trunk pipeline network, characterize geologic storage reservoirs, and establish permitting rules.[16]

Carbon Storage and Utilization RD&D Activities

Funding for carbon storage and utilization RD&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 RD&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, 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.[17]
- **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.[18]

- **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 costs of CCUS through the creation of value-added products via the conversion of CO_2.

Key Elements of the FY 2022 Budget Proposal[19]

The budget proposal seeks $155 million for carbon storage and utilization RD&D activities, a 52 percent boost from FY 2021 enacted levels. Some highlights include:

- **A 48 percent increase in Storage Infrastructure R&D,** including increased funding for the CarbonSAFE initiative to identify opportunities for onshore and offshore storage formations; and increased funding for the four Regional CCUS initiative projects.
- **A 104 percent increase in Advanced Storage R&D (which would be merged with Sub-disciplinary Storage R&D),** to support storage options beyond sedimentary basins and continue to fund the Science-informed Machine learning to Accelerate Real-Time (SMART) Initiative that advances artificial intelligence and machine learning-based technologies to optimize storage operations.
- **A 65 percent increase in Carbon Use & Reuse R&D,** which will support the development of at least one carbon utilization integrated system.

Further Reading

- Varun Sivaram et al., *Energizing America: A Roadmap to Launch a National Energy Innovation Mission* (ITIF and Columbia University SIPA Center on Global Energy Policy, 2020), http://www2.itif.org/2020-energizing-america.pdf.
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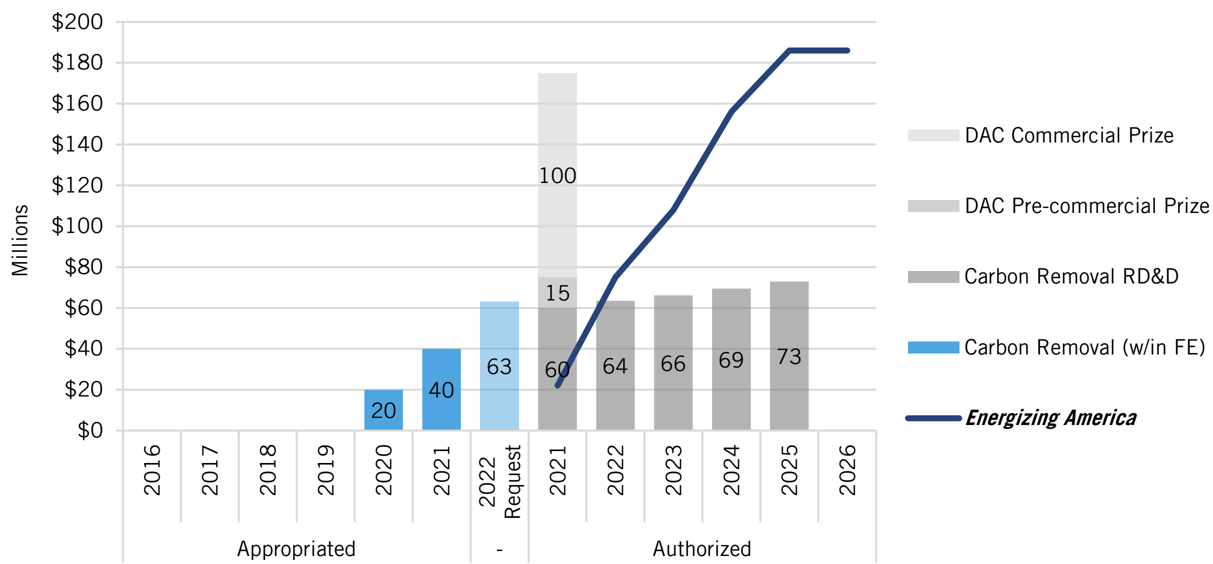
Federal Energy RD&D: Carbon Removal

BY COLIN CUNLIFF AND LINH NGUYEN | JUNE 2021

Carbon removal—sometimes called "negative emissions technologies"—refers to a suite of technologies and practices that remove carbon dioxide (CO_2) directly from the atmosphere for subsequent use or storage. Carbon removal is distinct from carbon capture, utilization, and storage (CCUS) and other conventional mitigation approaches because it removes CO_2 that is already in the atmosphere, rather than preventing the gas from being emitted in the first place.[1] The Energy Act of 2020 authorized the Department of Energy (DOE) to conduct research, development, and demonstration (RD&D) activities relating to direct air capture and storage (DACS), bioenergy with carbon capture and storage, enhanced geologic weathering, agricultural practices, forest management, and planned or managed carbon sinks.[2]

Figure 1: The Energy Act of 2020 directs DOE to establish a new Carbon Removal Program.[3]



What's at Stake

Removing CO_2 from the atmosphere and sequestering it permanently is no longer an option—it is a necessity. The 2018 Intergovernmental Panel on Climate Change (IPCC) found, "All pathways that limit global warming to 1.5°C with limited or no overshoot project the use of carbon dioxide removal on the order of 100 [gigatons]–1,000 gigatons of carbon dioxide ($GtCO_2$) over the 21st century."[4] But carbon removal is likely essential even for more relaxed targets. According to the IPCC, the median amount of carbon removal needed for pathways that limit warming to 2°C is 670 $GtCO_2$ by 2100, which is the equivalent of more than 100 times the total U.S. greenhouse gas emissions in 2019 (6.6 $GtCO_2$).[5]

Carbon removal addresses two essential challenges for deep decarbonization that other conventional mitigation approaches cannot. First, it is needed to offset residual emissions, especially non-CO_2 gases, that are impossible or prohibitively expensive to completely eliminate. For example, even the most aggressive decarbonization scenarios still include methane and nitrous oxide from agriculture.

Second, carbon removal provides a hedge against a carbon budget overshoot, which would occur if emissions did not decline quickly enough to avoid unacceptable and severe climate impacts. In this case, global average temperature rise would temporarily exceed some agreed-upon limit (e.g., 1.5°C or 2°C) before being brought down through net-negative emissions—i.e., when annual carbon removal exceeds residual emissions.

Unfortunately, no carbon removal technologies have been deployed at a scale that can meaningfully address the magnitude of global climate pollution. Approaches that manage natural ecosystems, such as afforestation and coastal restoration are low-cost, near-term options but have limited sequestration capacity, draw down atmospheric CO_2 too slowly to shape the path of climate change, and run into competition for land use. Technological approaches such as DACS, carbon mineralization through enhanced geologic weathering, and bioenergy with carbon capture and storage (BECCS) are relatively immature and expensive but have the potential to permanently remove large amounts of atmospheric CO_2.[6]

In October 2018, the National Academy of Sciences, Engineering, and Medicine (NASEM) released a detailed research agenda for carbon removal technologies, along with recommended funding levels to address each of the identified needs.[7] Many other scientific and advisory bodies have also recommended greater investment in carbon removal research, reflecting a growing consensus that carbon removal is important for achieving global climate goals.[8] In 2019, the Energy Futures Initiative (EFI) released the follow-on report *Clearing the Air* which provides a set of detailed implementation plans for the NASEM recommendations, including agency funding levels and program structures for a comprehensive 10-year $10.7 billion carbon removal innovation program that includes demonstration projects.[9]

Congressional appropriators have directed DOE to begin small-scale research efforts on direct air capture (DAC), carbon mineralization, bioenergy with carbon capture and storage (CCS), and other carbon removal approaches in the past few budget cycles.[10] In FY 2021 appropriations, Congress directed DOE to invest a total of $82.5 million in carbon removal across three offices: $40 million in the Office of Fossil Energy (FE), of which at least $15 million is for DAC; $20 million in the Office of Energy Efficiency and Renewable Energy to support DAC manufacturing technologies and algal carbon capture; and $22.5 million in the Office of Science.[11] In March 2020, FE released a new funding opportunity to provide $22 million in research for DAC.[12] However, current investments are too small to meaningfully address all carbon removal RD&D needs.

The Energy Act of 2020 authorizes the creation of a new Carbon Removal Program at DOE, which is a significant expansion and elevation of carbon removal research. The bill authorizes a new Direct Air Capture Prize Competition, with funding for both pre-commercial and commercial projects. The bill also directs DOE to establish one or more Direct Air Capture Test Centers and encourages DOE to support carbon removal pilot and demonstration projects.[13]

Figure 1 shows the FY 2022 budget request and the Energy Act of 2022 authorized funding levels for the new Carbon Removal Program. Funding for the pre-commercial and commercial DAC prize competitions is authorized in FY 2021, to remain available until expended. The carbon removal RD&D activities are authorized at $60 million in FY 2021, increasing to $73 million in FY 2025. The blue line shows recommended funding levels from the *Energizing America* report, which is adapted from *Clearing the Air*.

Box 1: An Innovation Agenda for Carbon Removal

The *Energizing America* report coauthored by the Information Technology and Innovation Foundation (ITIF)and Columbia University's Center on Global Energy Policy offers the creation of new federal programs to accelerate the development of carbon removal technologies.

- Congress should establish a comprehensive interagency RD&D initiative that implements the recommendations of the National Academies report on carbon removal. EFI provides a set of detailed implementation plans that include agency funding levels and program structures for a comprehensive 10-year, $10.7 billion carbon removal innovation program that includes demonstration projects.
- Congress should expand funding for the Carbon Removal Program at DOE, consistent with the levels recommended in the National Academies and EFI reports, and should encourage coordination with other parts of DOE. DOE should initiate an intra-agency working group to coordinate activities between the Carbon Removal Program, Carbon Capture and Carbon Storage programs in FE, Basic Energy Sciences (BES), Bioenergy Technologies Office (BETO), Advanced Research Projects Agency-Energy (ARPA-E), and other parts of DOE with relevant expertise.
- The White House should establish an interagency working group (IWG) to coordinate research between DOE, National Science Foundation, U.S. Geological Survey, U.S. Department of Agriculture, and other relevant agencies.

Carbon Removal RD&D Activities

The Carbon Removal Program was established in the Energy Act passed by Congress in December 2020. DOE has not yet announced plans for how the office and RD&D activities will be structured. The Energy Act authorizes funding for three broad activities: a prize competition for pre-commercial air capture; a prize competition for commercial applications of DAC; and carbon removal RD&D.

Key Elements of the FY 2022 Budget Proposal[14]

The budget proposal establishes a new Carbon Dioxide Removal subprogram that builds on past CCUS efforts by DOE. It would be funded $63 million and would focus on DAC materials and components, BECCS for both gasification and combustion, and enhanced carbon mineralization concepts.

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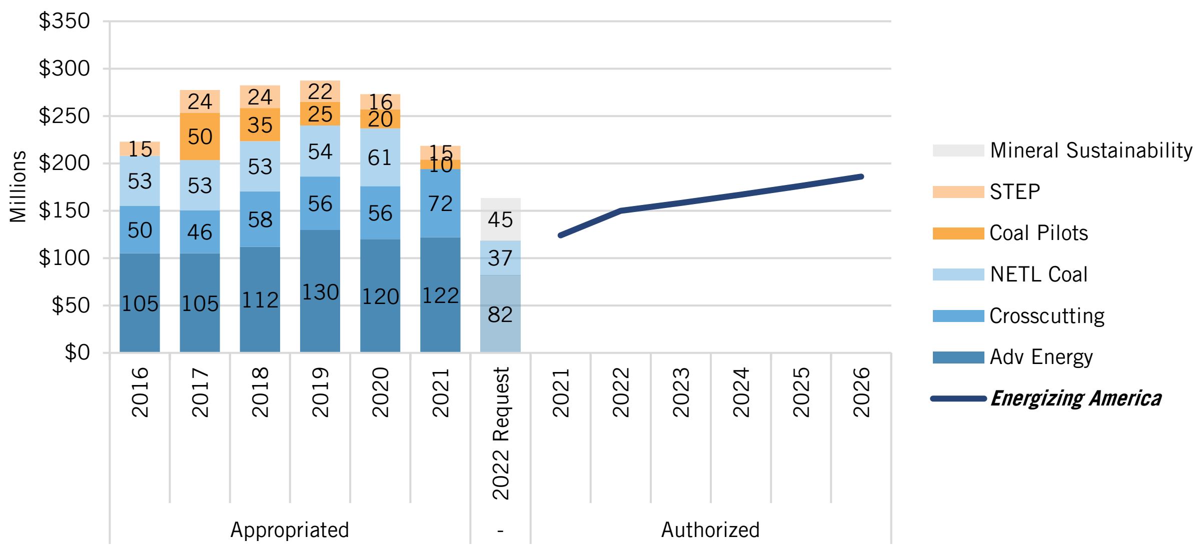
Federal Energy RD&D: Advanced Coal Energy Systems

COLIN CUNLIFF AND LINH NGUYEN | JUNE 2021

The Department of Energy's (DOE) advanced coal energy systems research, development, and demonstration (RD&D) program includes several subprograms aimed at 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 byproducts.[1]

Figure 1: The Energy Act of 2020 did not provide new authorizations for existing advanced coal energy systems research.[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, as older, uneconomical coal power plants retire. However, coal will likely remain a significant part of the nation's electricity mix until 2030, unless competitive pressure increases over time.[4] The National Academies of Sciences, Engineering, and Medicine found that achieving net-zero emissions by mid-century will require phasing out unabated coal-fired generation or retrofitting systems to capture 90 percent or more of carbon dioxide (CO_2) emissions by 2030.[5]

Some Advanced Coal Energy Systems RD&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 CO_2 gas mixture. The CO_2 can be separated prior to combustion, and the remaining hydrogen combusted in a combined-cycle power plant.[6] 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.[7] Additional

RD&D of SOFCs and gasification systems integrated with carbon capture will be necessary to lower costs and sufficiently improve performance to enable commercial deployment.

In the previous administration, the bulk of funding in the Advanced Coal Energy Systems programs supported the Trump 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 research and development (R&D) to develop advanced combustion technologies, supercritical CO_2 systems, and other coal technologies.[8] 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.

The Energy Act of 2020 provides the first reauthorization of DOE's Fossil Energy programs in more than a decade. However, the bill does not provide new authorizations for DOE's existing advanced coal energy systems research programs.

Figure 1 shows historical DOE investment in advanced fossil energy systems by subprogram for FY 2016 through 2021, and the FY 2022 budget request. The *Energizing America* report (blue line) recommends a refocusing on carbon-capture-ready technologies (see box 1).

Box 1: An Innovation Agenda for Advanced Fossil Energy Systems

The *Energizing America* report coauthored by the Information Technology and Information Foundation (ITIF) and Columbia University's Center on Global Energy Policy recommends that DOE and Congress continue to support carbon-capture-ready technologies but does not recommend funding for other fossil-based technologies.[9] Only coal with high-efficiency carbon capture rates (>95 percent) and strong pollution controls is consistent with a net-zero energy system that is fair and equitable. An innovation agenda for deep decarbonization should include support for carbon capture but exclude technologies that are inconsistent with the net-zero goal.

Advanced Coal Energy Systems Subprograms

Advanced Coal Energy Systems RD&D is spread across five subprograms:[10]

- **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.

- **Crosscutting 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.[11]

- **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.[12]

- **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.

ADVANCED COAL ENERGY SYSTEMS

Key Elements of the FY 2022 Budget Proposal

The budget proposal seeks $163.5 million for Advanced Coal Energy Systems RD&D activities, a 40 percent reduction from FY 2021 enacted levels. Some highlights include:

- **A 33 percent reduction in the Advanced Energy Systems subprogram,** with a proposed program name change to Advanced Energy and Hydrogen Systems. The program will not fund R&D for fossil fuel-based power generation and will instead support R&D to advance hydrogen-fueled turbines, fuel cells, and carbon capture, utilization, and storage technologies. Funding is reduced for Reversible Solid Oxide Fuel Cells and Transformative Power Generation. Funding for gasification systems would increase by $29 million to enable R&D in hydrogen production.[13]
- **A new Mineral Sustainability subprogram**, which will include carbon ore processing activities (formerly Advanced Coal Processing within the Advanced Energy Systems subprogram) and critical minerals R&D activities.[14]
- **A 49 percent reduction in the Crosscutting Research and Analysis subprogram,** primarily due to funding elimination for RD&D in fossil combustion. The subprogram will shift its focus to seven activities: 1) sensors, controls, and novel concepts; 2) water management RD&D; 3) simulation-based engineering; 4) energy analysis; 5) university training and research; 6) international activities; and 7) the Energy Storage Grand Challenge.[15]
- **No funding for the Transformational Coal Pilots subprogram.[16]**
- **No funding for Super Critical Transformational Electric Power (STEP) R&D.[17]**
- **No funding for National Energy Technology Laboratory (NETL) Coal R&D.[18]**

Further Reading

- Varun Sivaram et al., *Energizing America: A Roadmap to Launch a National Energy Innovation Mission* (ITIF and Columbia University SIPA Center on Global Energy Policy, 2020), http://www2.itif.org/2020-energizing-america.pdf.

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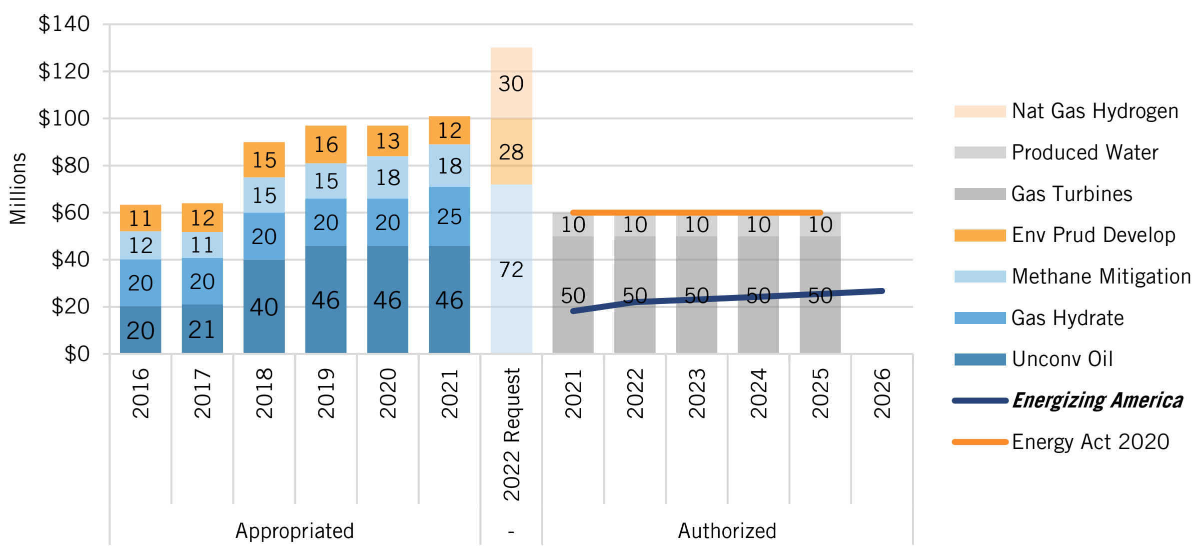
Federal Energy RD&D: Oil & Gas

BY COLIN CUNLIFF AND LINH NGUYEN | JUNE 2021

The Department of Energy's (DOE) oil and natural gas program supports research, development, and demonstration (RD&D) to ensure that 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 RD&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 Energy Act of 2020 prioritizes gas turbines and produced water RD&D but does not provide new authorizations for existing oil and gas programs.[2]



What's at Stake

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 RD&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 RD&D activities include treating and managing produced water, characterizing and minimizing induced seismic risk, and reducing surface footprints on well-pad sites and surrounding areas.[4]

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 RD&D on subsurface flow mechanics seeks to improve recoverability factors.

The gas hydrates program aims to characterize and evaluate domestic sources of methane hydrate deposits in Alaska and the Gulf of Mexico, which could lead to development of new sources of domestic natural gas.[5] However, the lifecycle impacts of potential methane hydrate resource development are highly uncertain. If methane hydrates were ever to be tapped as a new source of methane, a fugitive emission rate of as little as 3.2 percent across the entire production, transmission, distribution, and end-use chain would make the climate impacts of methane hydrate development worse than those of coal.[6]

The Energy Act of 2020 provides the first reauthorization of DOE's Fossil Energy programs in more than a decade. However, it does not provide new authorizations for DOE's existing oil and gas research programs. The bill establishes a new RD&D program to improve the efficiency of and reduce pollution from gas turbines used in power generation systems and aviation. The bill sets a goal of 67 percent efficiency for natural gas combined cycle power plants, and a 25 percent improvement in fuel efficiency for aviation gas turbines.[7] The bill also authorizes a new research and development (R&D) program to expand opportunities for the reprocessing of produced water at natural gas or oil development sites. (Research in produced water was formerly conducted in the Environmentally Prudent Development subprogram.)[8]

Figure 1 shows historical DOE investment in oil and gas by subprogram for FY 2016 through FY 2021, and the FY 2022 budget request. The orange line shows total authorized funding levels in the Energy Act of 2020 for FY 2021 through FY 2025, across the gas turbines and produced water programs. The blue line shows recommended RD&D funding levels from the *Energizing America* report, which encompasses recommendations for methane emissions quantification and mitigation but does not include recommended funding levels for the other oil and gas programs (see box 1).

Box 1: An Innovation Agenda for Methane Mitigation

The *Energizing America* report coauthored by the Information Technology and Information Foundation (ITIF) and Columbia University's Center on Global Energy Policy recommends continued investment in the development of methane leak detection and mitigation technologies and methods, consistent with the Fossil Energy R&D Act of 2019.[9]

Additionally, the National Academies of Sciences, Engineering, and Medicine (NASEM) found, "Repurposing existing fossil fuel infrastructure can reduce the overall costs of the transition while reducing the potential for stranded assets and workers." For example, upgrading or converting natural gas pipelines to carry hydrogen and natural-gas blends or 100 percent hydrogen could help retain the use of those pipelines in a low-carbon energy system, thereby avoiding the need for more costly and difficult-to-site new builds while also preventing stranded assets for pipeline owners and preserving jobs in natural gas transmission and distribution utilities. Using residual oil and gas basins for permanent underground storage of CO_2 could help oil companies transition into carbon management utilities.[10]

Oil & Gas RD&D Activities

RD&D in oil and natural gas is spread among four activities:[11]

- **Unconventional Fossil Energy from Petroleum R&D** supports the development of domestic production from unconventional reservoirs, which requires complicated engineering measures, such as hydraulic fracturing and directional drilling, to improve access and enable commercial production.
- **Methane Emissions Quantification and Mitigation** focuses on technologies that quantify and reduce methane leaks and vented emissions from natural gas systems. Methane 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.[12] Oil and gas systems together account for the largest share of domestic methane emissions, with the lost methane is valued at an estimated $2 billion.[13] 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.

OIL AND GAS

Key Elements of the FY 2022 Budget Proposal

The budget proposal seeks $130 million for oil and gas RD&D activities, a 26 percent boost from FY 2021 enacted levels. Some highlights include:

- **A 260 percent increase to the Methane Emissions Quantification and Mitigation subprograms**, including an $11.5 million increase for emissions quantification from natural gas infrastructure and a $40.5 million increase for emissions mitigation from midstream infrastructure.[14]
- **A 133 percent increase to the Environmentally Prudent Development subprogram,** which would support research on solutions to mitigate the environmental impacts of natural gas production.[15]
- **A new Natural Gas Hydrogen Research subprogram,** which will focus on hydrogen production, transportation, and storage R&D, funded at $30 million.[16]
- **No funding for Gas Hydrates research.**[17]
- **No funding for the Unconventional Fossil Energy Technologies from Petroleum R&D program.**[18]

Further Reading

- Varun Sivaram et al., *Energizing America: A Roadmap to Launch a National Energy Innovation Mission* (ITIF and Columbia University SIPA Center on Global Energy Policy, 2020), http://www2.itif.org/2020-energizing-america.pdf.
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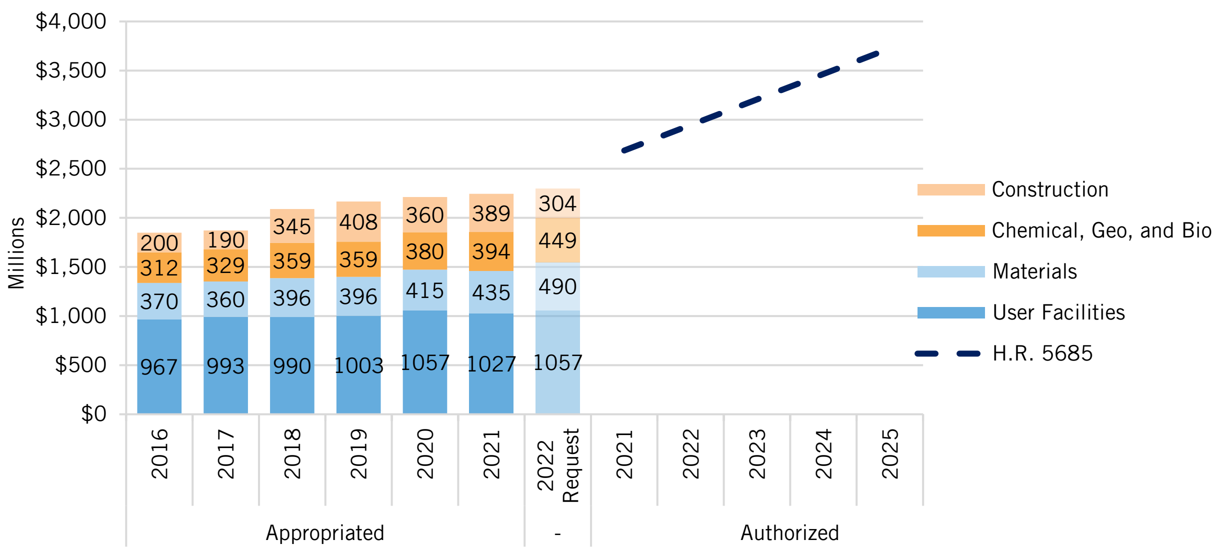
Federal Energy RD&D: Basic Energy Sciences

BY COLIN CUNLIFF AND LINH NGUYEN | JUNE 2021

The Department of Energy's (DOE) Office of 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: *Energizing America* recommends doubling funding for basic clean energy research in the Office of Science by FY 2026.[2]



What's at Stake

Fundamental scientific research across a range of fields—including advanced materials, electrochemistry, quantum computing, and advanced measurement and sensing—can enable breakthroughs in energy technologies. Better catalysts can lower the energy requirements for hydrogen and ammonia production. New solvents and membranes can make carbon capture—whether from power plants or directly from the atmosphere—cheaper and more efficient. New battery chemistries can improve the energy density and storage duration of batteries. On the international stage, Mission Innovation launched the Clean Energy Materials Innovation Challenge to integrate automated robotic laboratories with machine learning to identify new materials for batteries, solar cells, thermal storage, catalysts for conversion of captured carbon dioxide (CO_2), and other clean energy applications.[3] The innovation agenda for deep decarbonization should embrace the entire innovation spectrum, including use-inspired basic energy research.

BES is fundamental to progress in clean energy technologies and comprises 25 percent of the energy research, development, and demonstration (RD&D) program 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, including the commercialization of new technologies that shape the way we produce and consume energy—years, and often decades, after the initial research was done.[4]

Basic research by DOE in subsurface fluid flow and high-strength materials in the early 1980s resulted in advancements in hydraulic fracturing and horizontal drilling that enabled the shale-gas boom of the mid-2000s that continues to reshape U.S. electricity markets.[5] The discovery of quantum dots—small semiconductor particles a few billionths of a meter wide that allow for conversion of blue light into other colors—were critical to the development of cheap, efficient light-emitting diodes (LEDs) that now account for 30 percent of all installed lighting.[6] The discovery in 1986 of high-temperature superconductors led to a burst of research at the Department of Defense (DOD), Department of Energy (DOE), National Science Foundation (NSF), National Aeronautics and Space Administration (NASA), and National Institute of Standards and Technology (NIST), both in applications of superconductivity as well as basic science to explain the phenomena and develop new superconducting materials. Decades later, superconductors now have applications in offshore wind, electrical grid fail-safe devices, MRIs for medical imaging, and mobile communications towers.[7]

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. The EFRCs are organized around five "Transformational Opportunities" in basic energy sciences and span a diverse range of technologies—from molten salts for nuclear reactors to advanced catalysts for batteries.[8]

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, CO_2, 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 provide nearly 16,000 industry, government, and academic researchers access to advanced research capabilities, including X-ray lasers, accelerators, neutron sources, and tools to probe matter on the nanoscale.[9] Many of these tools are too expensive for a single university lab or private company to own and operate. So instead, BES operates these large user facilities to enable academic and industry researchers to access those advanced tools. X-ray and neutron sources, in particular, are key tools for researching energy storage materials, advanced catalysts, and quantum processes and materials.

The National Academy of Sciences has called for a doubling of basic science research, including at BES, as a means of addressing challenges to U.S. competitiveness.[10] 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.[11]

Figure 1 shows historical DOE investment in BES RD&D by subprogram, for FY 2016 through FY 2021, and the FY 2022 budget request. The Energy Act of 2020 did not include reauthorizations of Office of Science programs. H.R. 5685, the Securing American Leadership in Science and Technology Act of 2020, put forth by House Republicans on the House Science, Space, and Technology Committee, included separate authorizations for Office of Science programs.[12] The bill included $2,686 million for FY 2021, $2,946 million for FY 2022, $3,206 million for FY 2023, $3,466 million for FY 2024, and $3,726 million for FY 2025 in funding authorizations for BES. However, the bill died in the 116th Congress and has not been reintroduced. Proposed funding for BES in H.R. 5685 is shown as a dashed blue line in figure 1.

Box 1: An Innovation Agenda for Basic Energy Sciences

The *Energizing America* report coauthored by the Information Technology and Innovation Foundation (ITIF) and Columbia University's Center on Global Energy Policy offers several recommendations to BES. Similarly, ITIF's report "An Innovation Agenda for Deep Decarbonization: Bridging Gaps in the Federal Energy RD&D Portfolio" provides recommendations to maximize the effectiveness of BES RD&D activities:

- Congress should provide full funding for the next generation of DOE user facilities, as well as planned upgrades at existing facilities. These facilities are critical to addressing basic research needs. DOE should evaluate whether the capacity of existing user facilities is sufficient to accommodate all research applications with scientific merit, and present a plan to Congress for building additional user facilities if warranted.[13]
- BES should identify and prioritize key crosscutting basic and use-inspired research programs that have multiple applications. For example, the International Energy Agency (IEA) has found that advances in electrochemistry could lead to dramatic cost declines and performance improvements in batteries, fuel cells, and electrolyzers due to synergies and spillovers between these technologies.[14]
- BES should double the number of EFRCs and organize them around key decarbonization challenges, particularly for hard-to-abate sectors such as heavy industry (steel, cement, and chemicals manufacturing), hard-to-electrify transportation sectors (aviation, shipping, and long-haul trucking), and negative emissions technologies.[15]
- DOE should take a leadership role in the Mission Innovation Clean Energy Materials Innovation Challenge, and establish a domestic automated materials discovery facility.

Basic Energy Sciences RD&D Activities

RD&D in basic energy is distributed across four subprograms:[16]

- **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 2022 Budget Proposal[17]

The budget proposal seeks $2.3 billion for BES RD&D activities, a 2.4 percent increase from FY 2021 enacted levels. Some highlights include:

- **A 13 percent increase in funding for Materials Sciences and Engineering.** Scattering and Instrumentation Science research would get a $11 million boost; Condensed Matter and Materials Physics research, $17 million; Materials Discovery, Design, and Synthesis, $16 million boost; and Energy Frontier Research Centers, $7 million.
- **Flat funding of $25 million for 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 14 percent increase in funding for the Chemical Sciences, Geosciences and Biosciences subprogram.** Research in fundamental interactions would increase by $16 million, and photochemistry and biochemistry research by $24 million. Chemical transformation research would receive a $5 million boost.
- **A 6.8 percent cut to BES construction,** including reduced funding for upgrades at the Advanced Photon Source, the Spallation Neutron Source, and the Linac Coherent Light Source-II.

- **Flat funding for the Batteries and Energy Storage and the Fuels from Sunlight Energy Innovation Hubs.**

Further Reading

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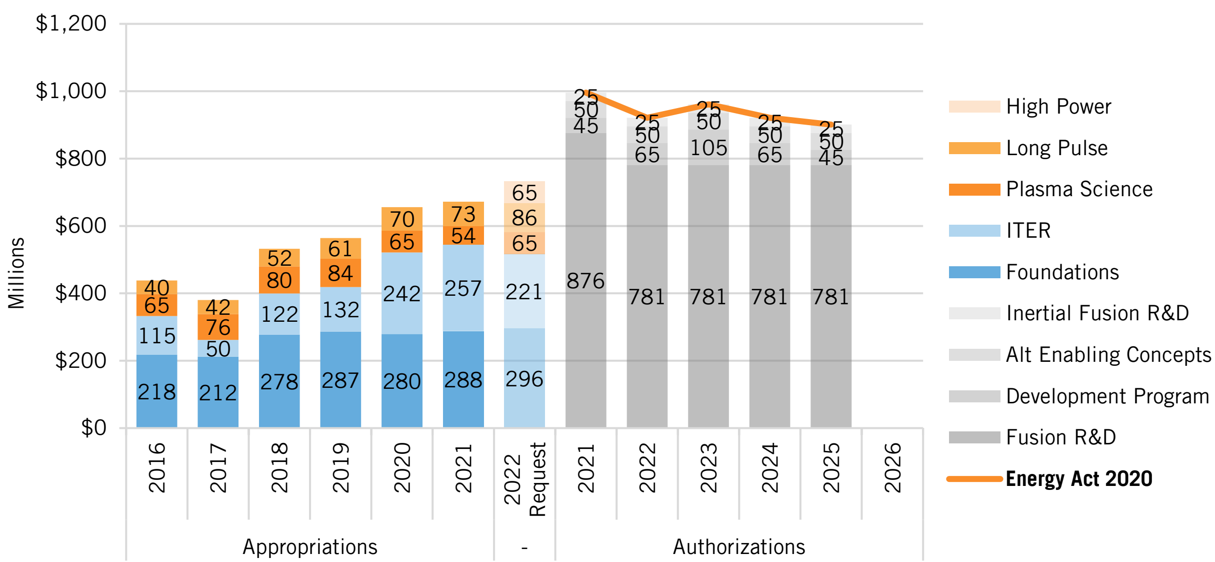
Federal Energy RD&D: Fusion Energy Sciences

BY COLIN CUNLIFF AND LINH NGUYEN | JUNE 2021

The mission of the Fusion Energy Sciences (FES) program is to 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. However, controllable fusion technology is still at a very early stage of development.

Figure 1: Fusion research has seen a boost in recent years, both in domestic research and in U.S. contributions to the International Thermonuclear Experimental Reactor (ITER).[3]



What's at Stake

Fusion research, development, and demonstration (RD&D) has the potential to contribute to U.S. energy security by making available a robust clean energy technology that relies on widely available and virtually inexhaustible fuel sources. However, the technological advances needed to realize safe, low-cost fusion are still nascent, so basic research into plasma physics—including plasma confinement and plasma-materials interactions—remains essential to advancing toward the goal of fusion energy.

DOE explains explained fusion energy as follows:

> Fusion is a nuclear reaction where two small atoms like hydrogen combine to form a larger atom like helium, and produce an enormous amount of energy as a byproduct. In controlled thermonuclear fusion, these reactions are facilitated by heating and confining fusion fuel in the form of a plasma, which is created when a gas absorbs enough energy to separate the electrons from the nuclei, making it susceptible to electric and magnetic fields. It requires a great deal of energy to attain the temperatures and pressures required for fusion, and confining plasmas to sustain these conditions is a monumental technical challenge. Most mainstream fusion research currently focuses on one of two approaches to confining plasmas: magnetic confinement, which uses magnetic fields and lower-than-air ion densities, and inertial confinement, which uses heating and compression and involves greater-than-solid densities.[4]

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.[5] Robust plasma-research funding may therefore be necessary to prevent the United States from losing out on future benefits in these and other industries.

The FES program in the DOE Office of Science has primarily pursued magnetic confinement fusion approaches. Research facilities include DIII-D, the largest magnetic fusion user facility in the United States; and the National Spherical Torus Experiment, the most powerful spherical tokamak user facility in the world. The program also supports enabling research and development (R&D) in high-temperature superconducting magnet technology and plasma fueling and heating technologies, as well as long-pulse tokamak research and materials research that seeks to understand how plasmas interact with materials that might be used in future fusion facilities.[6] The National Nuclear Security Administration (NNSA), a semiautonomous agency within DOE responsible for stewardship of the nation's stockpile of nuclear weapons, also supports research in inertial confinement fusion, using lasers at its National Ignition Facility.[7]

DOE also participates in the International Thermonuclear Experimental Reactor (ITER), a collaboration among seven governments (China, the European Union, India, Japan, the Republic of Korea, Russia, and the United States) to demonstrate the scientific and technological feasibility of fusion energy for electricity generation. ITER is the only mature burning-plasma experiment in the world, with a goal of completing the first assembly phase in 2025 and second testing phase from 2025 to 2035.[8] The National Academies of Sciences, Engineering, and Medicine (NASEM) has found that no single country has the expertise or capacity to conduct a fusion experiment at this scale.[9] 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.[10]

In 2020, DOE launched a new pilot program, 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 DOE's national laboratories.[11] INFUSE is motivated in part by recent research suggesting compact fusion technologies could be developed and commercialized on a much smaller scale than large, capital-intensive projects such as ITER. For example, Commonwealth Fusion Systems (CFS), in collaboration with the Massachusetts Institute of Technology's Plasma Science Fusion Center, published a series of papers laying out their approach to develop a compact fusion device.[12] INFUSE provides an alternative model for supporting fusion research, by allowing innovative start-ups such as CFS to tap into national research facilities and validate their approach.

The Energy Act of 2020 provides the first reauthorization to the FES program in over a decade and entails a significant restructuring of the program. The bill authorizes funding for DOE to support fusion energy RD&D activities. The bill creates a new inertial fusion research and development (R&D) program in FES to research ion beam, laser, and pulsed power fusion systems, and authorizes $25 million annually for FY 2021 to FY 2025. Moreover, $50 million is allocated annually for FY 2021 to FY 2025 to support alternative fusion energy concepts, enabling fusion technology development, and advanced scientific computing activities. The bill includes a milestone-based development program to support R&D of technologies for the construction of new full-scale fusion systems. The program is authorized $45 million for FY 2021, $65 million for FY 2022, $105 million for FY 2023, $65 million for FY 2024, and $45 million for FY 2025.[13]

Figure 1 shows historical DOE investment in fusion energy RD&D by subprogram, for FY 2016 through FY 2021, and the FY 2022 budget request. The orange line shows authorized funding levels from the Energy Act of 2020.

Fusion Energy Sciences RD&D Activities

RD&D in fusion energy is distributed across four subprograms:[14]

- **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.
- **ITER** is an ambitious international collaboration among seven governments (China, the European Union, India, Japan, the Republic of Korea, Russia, 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 2022 Budget Proposal[15]

The budget proposal seeks $675 million for FES RD&D activities, a 0.4 percent boost from FY 2021 enacted levels. Some highlights include:

- **A 3 percent increase in Burning Plasma Science: Foundations,** including a $11 million boost for Theory and Simulation, most of which would go into Scientific Discovery through Advanced Computing (SciDAC) partnerships. Funding for research and operations at DIII-D, the largest magnetic fusion user facility in the United States, and the National Spherical Torus Experiment Upgrade (NSTX-U), the most powerful spherical tokamak user facility in the world, would continue.
- **A 19 percent increase in Burning Plasma Science: Long Pulse,** including $15 million to long-pulse tokamak research, as well as a $10.5 million increase 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 19 percent increase in Discovery Plasma Science,** including a $7.3 million increase in general plasma science, which explores low-temperature plasma science and engineering.
- **A 9 percent-reduced contribution to the International Thermonuclear Experimental Reactor (ITER),** which would still allow the U.S. to meet its agreed-upon contributions to 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. 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. The requested funding will continue to support the design and fabrication of In-kind hardware systems for the First Plasma subproject.
- **A new $2 million ITER Research program** to start preparing the U.S. fusion community to take full advantage of ITER operations after First Plasma.

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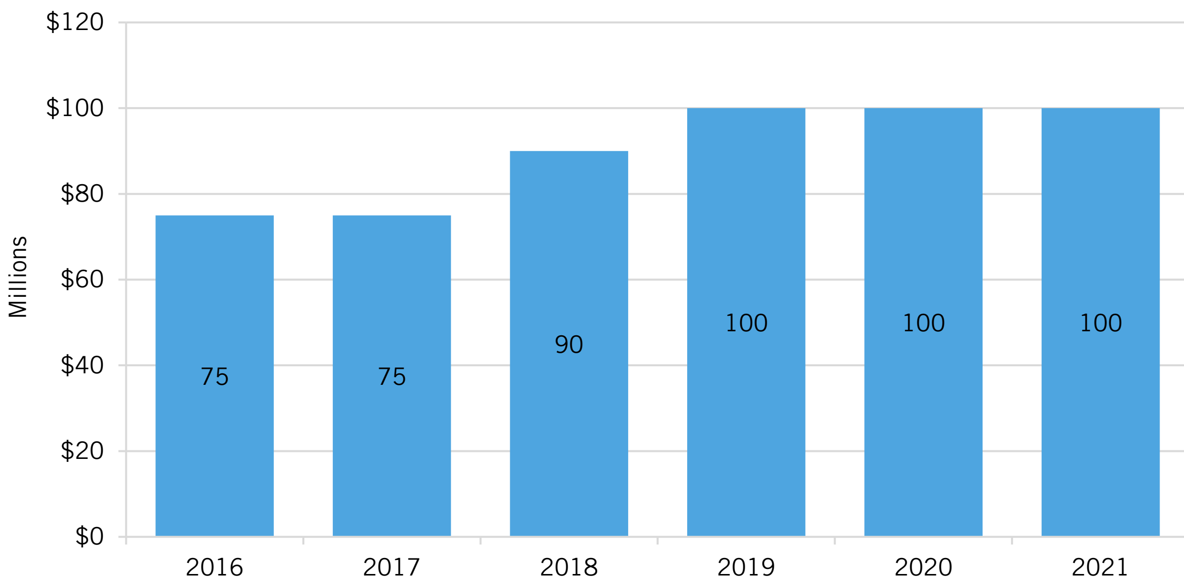
Federal Energy R&D: Bioenergy Research Centers

BY: LINH NGUYEN AND COLIN CUNLIFF DATE: JUNE 2021

The Department of Energy's (DOE) Bioenergy Research Centers (BRCs) pursue fundamental research into microbial and plant biology as a basis for improving the extraction of energy from inedible plant biomass. BRC research topics include bioenergy crop production with minimal environmental impact, deconstruction techniques to efficiently break down and convert biomass into useful energy, and biotechnology approaches to sustainably produce advanced biofuels and bio-based products and materials.[1] BRCs also explore solutions to enhance carbon storage and sequestration in soil and increase plant nutrient uptake to reduce fertilizer consumption.[2]

Figure 1: *Energizing America* recommends doubling funding in clean energy research, including the basic energy science research conducted in the Office of Science, by FY 2026.[3]



What's at Stake

Biomass is versatile and can play a pivotal role in decarbonizing multiple sectors of the economy. It can be converted to transportation fuels, combusted for heat and power generation, gasified to produce hydrogen, and transformed into bioproducts such as bioplastics. The United States has the potential to produce 1 billion dry tons of nonfood biomass annually by 2030. That is enough to make approximately 50 billion gallons of biofuels (25 percent of U.S. transportation fuels), 50 billion pounds of high-value chemicals and products, and 7 billion kilowatt-hours (kWh) of electricity—enough to power 7 million homes.[4] Unlocking this potential will require addressing fundamental challenges that limit the sustainable and cost-competitive production and conversion of biomass into useful energy.

DOE's Office of Biological and Environmental Research (BER) funds four BRCs: 1) the Joint BioEnergy Institute (JBEI), 2) the Great Lakes Bioenergy Research Center (GLBRC), 3) the

Center for Bioenergy Innovation (CBI), and 4) the Center for Advanced Bioenergy and Bioproducts (CABBI). As of the end of FY 2019, these BRCs had produced 3,370 peer-reviewed publications, 715 invention disclosures, 510 patent applications, 244 licenses or options, 176 patents, and 19 company start-ups.[5] They facilitated knowledge sharing across multiple disciplines to make significant progress in the production of bioenergy and bioproducts.

CBI's research on switchgrass, for example, led to the identification of a number of genes that make plant cell walls resistant to deconstruction and conversion to biofuels. JBEI developed a new interference technique based on CRISPR (clustered regularly interspaced short palindromic repeats) to increase the production of isopentenol, an advanced biofuel that could serve as an alternative to gasoline. GLBRC engineered a strain of bacteria that is a precursor for developing valuable chemicals derived from lignin—a polymer found in plant biomass—to jump-start a bioplastics industry. And CABBI is using a "plants as factories" approach to produce biofuels, bioproducts, and high-value chemicals directly in plant stems.[6]

BRCs also support research to enhance carbon sequestration and nutrient uptake by plants and soil. GLBRC is conducting research on soil enzyme activities and characteristics that affect soil carbon sequestration and has found that soil on marginal lands unsuitable for growing food crops has the potential to sequester more carbon. CABBI has identified a number of genes for nitrogen transport in sugarcane that are now used as genomic targets for improving nitrogen uptake and use, which not only improves yields but also reduces demand for nitrogen-based fertilizers. Nitrogen fertilizers are carbon intensive to manufacture, and their use can result in the release of nitrous oxide, a potent greenhouse gas.[7]

Box 1: An Innovation Agenda to Accelerate Biological Solutions for Climate

The Information Technology and Innovation Foundation's (ITIF) September 2020 report "Gene Editing for the Climate: Biological Solutions for Curbing Greenhouse Gas Emissions" examines promising opportunities for gene editing to mitigate emissions from agriculture and other sectors, and to capture carbon from the atmosphere. Gene editing could enhance the efficiency of photosynthesis, reduce methane emissions from cows and rice paddies, optimize biofuel crops, and solve many other climate challenges. Though not explicitly directed at the BRCs, these recommendations may be useful as DOE develops its research agenda:

- Governments should increase investment in research and development (R&D) for gene-edited solutions for climate change several-fold, especially in nitrogen fixation, improved photosynthesis, genetics of root architecture, methods for measuring soil carbon content, livestock breeding and improved management of ruminant microbiomes, and microbial and algal systems for carbon capture, utilization, and storage (CCUS) in powerplants and industrial facilities. DOE should expand its research into artificial photosynthesis to produce fuels from sunlight.[8]
- Governments should increase investment and R&D funding for CRISPR, a powerful technology for editing genomes.[9]

- The White House Office of Science and Technology Policy (OSTP) should develop and oversee a national strategy to improve interagency coordination in gene-edited climate solutions. OSTP's 2019 Bioeconomy Initiative would provide a good initial building block.
- Federal agencies that invest in gene-editing R&D should work with the Realizing Increased Photosynthetic Efficiency (RIPE) Project to create a worldwide climate-solutions initiative in collaboration with philanthropic and industrial partners.

Bioenergy Research Centers

BER funds four bioenergy research centers:[10]

- **Center for Advanced Bioenergy and Bioproducts (CABBI),** led by the University of Illinois at Urbana-Champaign, develops efficient ways to grow bioenergy crops and convert biomass into valuable chemicals. It uses a "plants as factories" approach to produce fuels and chemicals in plant stems and an automated foundry to convert biomass into valuable chemicals that are economically and ecologically sustainable through recent advances in agronomics, genomics, and synthetic and computational biology.[11]
- **Center for Bioenergy Innovation (CBI),** led by Oak Ridge National Laboratory, explores a host of new technologies to produce bio-based products and advanced biofuels from biomass and lignin residues. Using genetic technology and bioengineering, CBI is developing high-yielding feedstock plants that optimize water and nutrient use. CBI also explores methods for both producing advanced biofuels that can be blended with existing transportation fuels and developing high-value biproducts from lignin waste.[12]
- **Great Lakes Bioenergy Research Center (GLBRC),** led by the University of Wisconsin-Madison in partnership with Michigan State University, focuses on engineering bioenergy crops to increase their environmental and economic value, generating multiple products from plant biomass, and understanding and optimizing the field-to-product pipeline. GLBRC identifies and engineers new biomass conversion microbes to make bioplastics that could potentially replace petroleum-based plastics.[13] GLBRC continues to conduct studies on growing energy crops on nonagricultural land to eliminate land-use competition between food production and biofuels.
- **Joint BioEnergy Research Institute (JBEI),** led by the Lawrence Berkeley National Laboratory, develops innovative technologies to produce clean, sustainable, and carbon-neutral biofuels and bioproducts. JBEI engineers microbes to convert sugar into "drop-in" advanced biofuels compatible with existing fueling infrastructure and vehicles across a range of transportation modes. JBEI also harnesses solar energy in biomass sources such as grasses and other inedible plants.[14]

Further Reading

- Val Giddings, Robert Rozansky, and David M. Hart, "Gene Editing for the Climate: Biological Solutions for Curbing Greenhouse Emissions" (Information Technology and Innovation Foundation, September 2020), https://itif.org/publications/2020/09/14/gene-editing-climate-biological-solutions-curbing-greenhouse-emissions.
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