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Further Energizing Innovation in Fiscal Year 2023

BY HOYU CHONG AND DAVID M. HART | MAY 2022

The FY 2023 budget request signals America's commitment to sustaining bipartisan momentum for clean energy innovation. Congress should seize this opportunity to accelerate domestic clean energy industries and shape the U.S. response to climate change.

KEY TAKEAWAYS

- The FY 2023 budget request calls for $10.5 billion in clean energy RD&D investment for the Department of Energy, which represents a 25 percent increase over FY 2021 enacted levels and 14 percent over FY 2022 enacted levels.
- Along with the appropriations from the Infrastructure Investment and Jobs Act (IIJA), total RD&D investments could be over $19 billion—an unprecedented level that would put the figure on track to reach $25 billion by 2025.
- Even so, this elevated level represents just 0.08 percent of U.S. GDP, well below the high-water mark of 0.14 percent in 1978. Had federal investment kept pace with growth in the economy, DOE's RD&D budget today would be $30 billion.
- While the FY 2023 request would raise investments in solar and wind RD&D—and the IIJA provides large increases for hydrogen, carbon management, and vehicle technologies—the buildings, bioenergy, and geothermal fields are lagging.
- Continuing along the growth trajectory is vital to accelerate innovation and develop the climate solutions the world needs while strengthening the competitiveness of U.S. technology developers and manufacturers.

EXECUTIVE SUMMARY

The Biden administration's FY 2023 budget request for the Department of Energy (DOE) calls for a 25 percent increase in investment in clean energy RD&D over FY 2021 enacted levels. Along with the passage of the Energy Act of 2020 and the Infrastructure Investment and Jobs Act (IIJA), this proposal is an encouraging sign for the progress of climate-tech innovation and would sustain the momentum of federal clean energy research, development, and demonstration (RD&D) programs. Continuing along this trajectory is vital to develop the climate solutions the world needs while strengthening the competitiveness of U.S. technology developers and manufacturers.

The context for federal clean energy innovation investments is daunting. Unabated fossil fuels still dominate global consumption. New technologies that would drastically reduce greenhouse gas (GHG) emissions from many major sources cost too much, perform too poorly, or are simply unavailable. Although the global energy innovation system still has major gaps, many countries have advanced assertive programs targeting specific sectors that collectively threaten U.S. leadership, including in public funding for energy RD&D, where the United States has long been the top investor.

Such funding has proven its value in the past. Yet, had it kept pace with the growth of the U.S. economy since DOE's founding in 1978, the department's RD&D budget today would be about $30 billion, more than three times its level in fiscal year 2022. The bipartisan consensus that led to recent legislation and funding increases must be sustained in order to approach that level again, as numerous expert studies have advocated. The administration's budget would raise it to over $10 billion in fiscal year 2023. Congress should seize the opportunity to sustain the momentum, accelerate domestic clean energy industries, and shape the U.S. response to climate change.

This report describes DOE's RD&D programs, assesses significant updates to them, and discusses notable gaps that still remain. It is supported by an interactive that will be updated throughout the FY 2023 budget cycle at itif.org/rdd-fy23.

INTRODUCTION

The fiscal year (FY) 2023 budget is an important opportunity for Congress and the administration to keep up the momentum of U.S. investment in energy innovation. The Energy Act of 2020 and the recently passed IIJA, both of which won bipartisan support, have paved the way for a major expansion in federal RD&D funding to combat climate change and strengthen U.S. competitiveness. Many members of Congress have joined President Biden in calling for a reinvigoration of the national energy innovation system to reverse decades of declining investment and position the United States to thrive in the global clean energy transition.

Many U.S. competitors have been investing heavily in RD&D to develop low-carbon technologies and capture growing global clean energy markets. Most notably, China nearly doubled its investment between 2015 and 2019. It 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] Meanwhile, Europe is outperforming the United States in offshore wind and has set aggressive targets in hydrogen and low-carbon steel.

The U.S. government has begun to respond to the global and international challenges of the low-carbon economy of the future by boosting its investment in energy RD&D by 39 percent between fiscal years 2017 and 2022. Yet, as a share of the U.S. economy, federal investment has grown little, hovering around 0.04 percent of gross domestic product (GDP), far behind leading European countries such as Norway and Finland.[2] With the legislative foundation provided by the Energy Act and IIJA in place, Congress and the administration have an opportunity to forge a path in fiscal year 2023 that will break through this barrier.

This report builds on *Energizing America*, the Information Technology and Innovation Foundation's (ITIF's) 2020 book-length collaboration with Columbia University's Center on Global Energy Policy, as well as more recent ITIF annual reports on the energy RD&D budget and related analyses. It provides an overview of federal energy innovation programs, including the key role of DOE in advancing energy technologies, and highlights 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 2023 budget and appropriations cycle.

Twenty-two infographics accompany this report online. Each includes a description of a DOE RD&D program and its technology goals, including renewable energy, transportation, energy efficiency, grid modernization, nuclear energy, fossil energy and carbon management, and basic sciences. The infographics also highlight what's at stake in each program, along with its potential impacts, historic and authorized funding levels, and targeted recommendations for Congress and DOE to accelerate innovation. They form the core of the that will be updated throughout the FY 2023 budget cycle at itif.org/rdd-fy23.

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

The transition from a global energy system dominated by unabated fossil fuels to one with net-zero emissions is vital to mitigate climate change, protect human health, and help revitalize the U.S. economy. However, clean energy alternatives have not yet been commercialized for certain sectors that produce large amounts of GHG 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 are the high-emitting technologies they would replace and face other barriers to scaling up. Costs and barriers must continue to fall for these clean technologies to cut emissions drastically.

The energy transition also brings with it risks and opportunities for U.S. industry. Investment in key technologies—from hydrogen to EVs to batteries to carbon capture and storage (CCS)—is rapidly increasing around the world. Global investment in clean energy marched to its highest level last year despite the ongoing pandemic, even as many traditional-energy industries suffered from delayed or declining investment.[3] The Russian invasion of Ukraine has added even more uncertainty to the global picture.

The passage of the IIJA signaled the United States' ambition to reclaim its position as a leader in clean energy innovation. Furthermore, in response to the ongoing supply chain challenges, the United States has recently initiated a strategy on manufacturing competitiveness, and President Biden has invoked the Defense Production Act to boost production of critical minerals used in EV

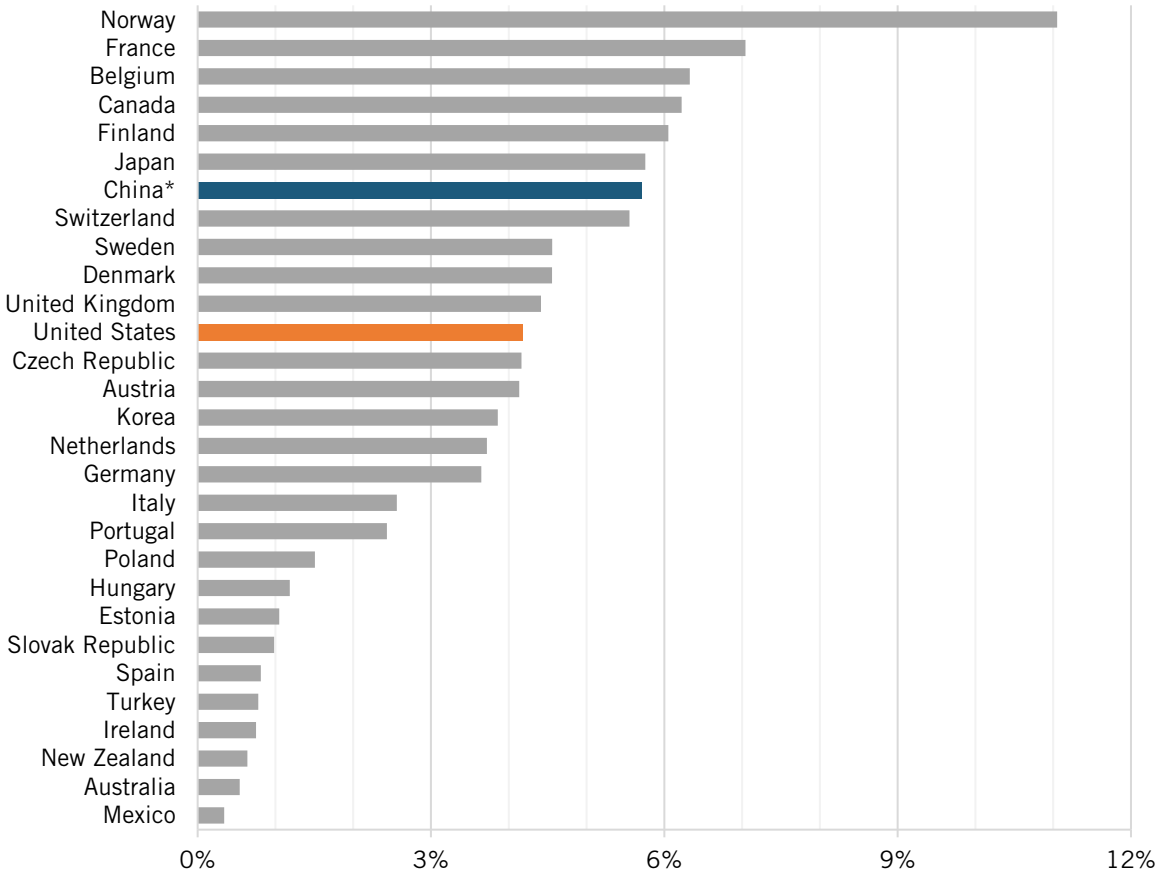
batteries. A key question for policymakers is whether the United States can weather today's supply chain challenges and continue to champion investments in tomorrow's clean technologies.

Fundamentally, the solution to both the supply chain and energy transition 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 development and demonstration, along with the creation of markets to hasten early adoption and ignite private sector innovation and competition.[4]

The Global Context for Federal Energy RD&D Investment

Global investment in energy was $1.9 trillion in 2021, rebounding nearly 10 percent from 2020 levels—putting it almost back to pre-pandemic levels.[5] But the share going to clean energy fell 1 percent from 2020. Investment in renewable power grew 2 percent in 2021 to $367 billion (in 2019 dollars). Global investment in EVs and charging infrastructure surged by 77 percent to $273 billion in 2021 and is on course to overtake investment in renewables in 2022.[6]

Figure 1. Government energy RD&D investment as a percentage of GDP, 2020[7]



As countries around the world seek to stimulate their economies and recover from COVID-19 amid the ongoing supply chain issues, many countries are also stepping up in clean energy technology investments. The European Union announced more than $200 billion in climate-

friendly economic recovery investments, such as clean hydrogen infrastructure.[8] 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.[9]

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 nearly doubled its investment in low-carbon energy RD&D between 2015 and 2019 annually, quickly catching up to the United States.[10] Eleven other countries invest more in energy RD&D as a share of their economies than does the United States (figure 1).[11] As other countries have stepped up their investments in clean energy, the United States' share of cleantech patents filed in at least two jurisdictions fell from 25 percent in 2013 to 20 percent in 2018, indicating that U.S. leadership in innovation truly is waning.[12]

These trends, combined with the decline of the U.S. manufacturing sector, has seriously jeopardized the United States' position as a leader in many clean energy technologies. 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."[13]

The Biden administration's supply chain task force responded with initiatives on building resilient supply chains, revitalizing American manufacturing, and fostering broad-based growth.[14] In February 2022, DOE followed up with its first-ever comprehensive strategy, which contains 13 assessment reports on securing the supply chain for a robust clean energy transition.[15] The United States must combine its bountiful natural assets with its 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

According to the International Energy Agency (IEA), only 2 out of 46 critical energy technologies (EVs and lighting) are currently "on track" with IEA's Net Zero Emissions by 2050 Scenario (figure 2.)[17] The Intergovernmental Panel on Climate Change's recent Sixth Assessment report sounds the alarm: Without immediate and deep emissions reductions across all sectors, it will be impossible to avert climate change, and these reductions depend on innovation.[18] The message is both clear and dire: 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.

The global energy innovation agenda since 2009 has focused, with considerable success, on reducing the cost and expanding the use of wind and solar resources for electricity generation. Rapid cost declines in solar PV, wind turbines, and grid-scale batteries are enabling decarbonization of the power sector in a much faster timeframe than was imagined a decade ago.[19] As a result, the electric power sector has made more progress in GHG emission reductions have than other major sectors.

Figure 2: International Energy Agency ratings of global progress on key technologies[20]

Electric Power		Industry		Buildings	
Solar PV	!	Chemicals	✗	Building Envelopes	✗
Wind Power	!	Iron and Steel	✗	Heating	!
Hydropower	!	Cement	✗	Cooling	!
Bioenergy Power Generation	!	Pulp and Paper	✗	Lighting	✓
Concentrated Solar Power	✗	Aluminum	✗	Appliances and Equipment	!
Geothermal Power	✗	CCUS in Industry and Transformation	✗	Heat Pumps	!
Ocean Power	✗	**Transportation**	✗	District Heating	✗
Nuclear Power	✗	Electric Vehicles	✓	Data Centers and Data Transmission Networks	!
Natural Gas-Fired Power	!	Rail	!	**Energy Integration**	!
Coal-Fired Power	✗	Fuel Consumption of Cars and Vans	✗	Energy Storage	!
CCUS in Power	✗	Trucks and Buses	✗	Hydrogen	!
Fuel Supply	✗	Transportation Biofuels	✗	Smart Grids	!
Methane Emissions from Oil and Gas	✗	Aviation	✗	Demand Response	!
Flaring Emissions	✗	International Shipping	✗	Direct Air Capture	!

✗ Not on track ! More efforts needed ✓ On track

Still, as ITIF's Stefan Koester has shown, continued innovation in renewable energy is not a given; public policy must continue to support technological improvements.[21] Of the $41.7 billion appropriated for clean energy RD&D from the IIJA (see box 1), just 0.4 percent is for solar and wind—compared with battery technologies (15 percent), carbon capture, utilization, and storage (CCUS) and direct air capture (16 percent), and smart grid and energy security (7 percent). The administration's FY 2023 budget proposal takes heed and proposes expanding RD&D investment in solar and wind (see box 2).

Box 1: IIJA Makes Major Investments to Accelerate Clean Energy and Climate Innovation

The IIJA has appropriated $62 billion to DOE from FY 2022 to FY 2026, of which $41.7 billion could be devoted to RD&D.[22] This sum vastly exceeds prior investments in key fields and will accelerate clean energy and climate innovation. Notably, the IIJA will provide:

- $21.5 billion for clean energy demonstrations;
- over $7 billion in the battery supply chain;
- $6.5 billion in CCUS and carbon dioxide removal (CDR);
- $3.3 billion in smart grid investment, energy security, and cybersecurity programs; and
- $420 million in renewable energy.

While the IIJA boosts what will become increasingly important tools in decarbonizing the United States and the world, much will still remain to be done when the law sunsets after FY 2026. Regular federal appropriations must avert a fiscal cliff for federal energy innovation in the years that follow.

An even more important 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 this decade, although 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 their 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 are light-duty cars and trucks, which 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 fossil fuel combustion that creates high-temperature heat. Many promising solutions are being developed, but they must be validated and demonstrated at commercial scale before they will make a dent in emissions.[26]

IEA's *Net-Zero by 2050* report finds that nearly half of the emissions reductions needed to achieve that ambitious goal will come from technologies that are today in the demonstration, large-prototype, or small-prototype stage of development.[27] Yet, in the past, new energy technologies—even recent successful consumer products such as LEDs and lithium-ion batteries—have taken 20 to 70 years to go from the first prototype to 1 percent market share.[28] The world cannot wait that long for key clean energy and climate technologies to mature.

Box 2: Raising the Bar in Solar and Wind RD&D Investments

The evolution of solar and wind technologies exemplifies the role of public policy in accelerating innovation and the synergistic interactions between public and private investment. Thanks in large part to these policies working together in the United States and globally, the cost of solar photovoltaic (PV) panels has declined by 99 percent over the last four decades, although most manufacturing now occurs elsewhere—especially in China, where mercantilist policies have helped that nation's firms gain global market share even as they lowered costs.[29] The levelized cost of land-based wind energy has also fallen substantially over the last four decades, but capital expenditures for such projects stopped falling years ago.[30] Despite these achievements, there is still ample room for further innovation to improve performance and lower costs. Advanced solar and wind technologies such as perovskite PV and floating offshore wind have the potential to overcome the land-use conflicts and geographical limits that confront more established solar and wind technologies.[31]

The FY 2023 budget request seeks to double and triple RD&D investments in Solar Technologies Office (SETO) to $645 million and Wind Technologies Office (WETO) to $365 million, respectively, from FY 2022 levels. In the United States, solar and wind accounted for almost 60 percent of electricity generation capacity additions from 2011 to 2020 but only 13 percent of net generation in 2021.[32] Expanded funding would aim to drive improvements that would enable

deeper solar and wind penetration in electricity grids. Moreover, the heightened funding levels would facilitate the siting and integration of renewable power generation and support the development of diversified, resilient supply chains for all renewable energy technologies. Finally, as part of the supply chain competitiveness strategy, the request would provide funding for a new Solar Manufacturing Accelerator, an initiative that partners the Advanced Manufacturing Office (AMO) with SETO.

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

Many technologies that now make major contributions to the U.S. and global energy systems were created as a result of federal investments and public-private cooperation.[33] Federally funded nuclear power RD&D, for instance, led to large-scale private investment in the commercial power plants that now account for 19 percent of U.S. electricity generation and half of zero-carbon power generation.[34] Decades of investment and policy-driven market development have led to precipitous declines in the cost of new solar PV (90 percent cheaper since 2009) and new wind facilities (72 percent cheaper since 2009).[35]

But unlike software and biotechnology, clean energy faces substantial scale-up and commercialization challenges.[36] Technology development lifecycles in this sector are long, and projects are often capital intensive and bear a significant amount of technical and financial risk.[37] Even venture capital funding, which tends to be less risk averse than other sources of private capital, seeks quick payback times and generous returns on investments that make it a poor match for the cleantech industry.[38] (Although venture capital investments in cleantech have made a roaring comeback in recent years, the lion's share of these investments has gone to the transportation sector.[39])

For these reasons, the energy industry invests a very small share of its revenues, just 0.5 percent, in research and development (R&D).[40] 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) and environmental externalities such as climate change are not valued in the market, 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.[41] Electric utilities are often legally mandated to keep prices low while some (e.g., those in California) are required to maintain a minimum return on equity, which may make it difficult or even impossible to invest in new technologies.[42]

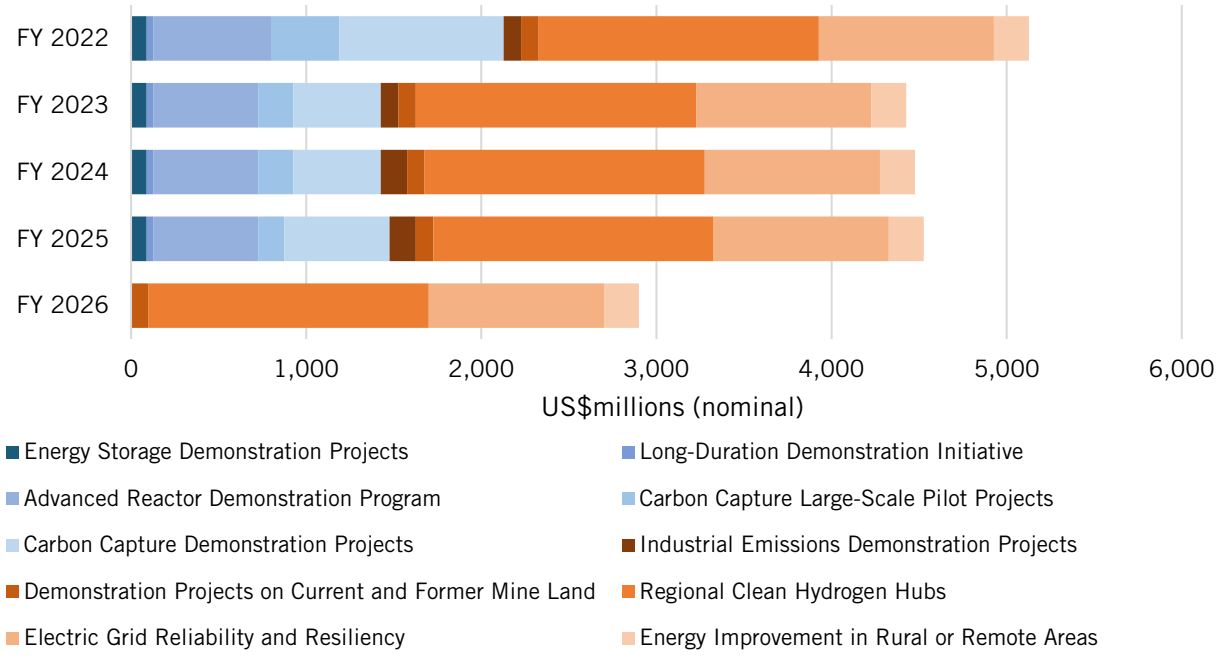
In clean energy, therefore, the burden of financing high-risk, long-term investments falls more heavily on the public sector than it does in typical high-tech industries. Although they are occasionally overcome by bursts of irrational enthusiasm, the market failures in these industries are more profound than most others are.

One often-overlooked market failure is in technology demonstrations. The payoffs from such projects tend to be too small and slow for even deep-pocketed, patient private investors to want to risk. Yet, the U.S. government has paid little attention to this gap, even as it has frequently accepted the risk associated with conventional R&D. In ITIF's Global Energy Innovation Index,

the United States ranks right in the middle (14th) of the 27 countries ranked according to their performance in energy demonstration policy. [43]

This has been a significant missed opportunity for global leadership, but the rankings will surely change as measurement catches up with the policy changes wrought by the IIJA, which established a new DOE Office of Clean Energy Demonstration (OCED) that should help promising technologies such as carbon capture and long-duration energy storage cross the fabled demonstration "valley of death."[44] (See box 3.) Although the FY 2023 budget proposes a rather small appropriation for OCED, it will receive $21.5 billion over five years thanks to the IIJA (figure 3.)

Figure 3: IIJA appropriation for OCED breakdown by program



Box 3: Scaling Innovation With the Office of Clean Energy Demonstration

Technology demonstration projects—especially large-scale demonstration projects—that are too risky for the private sector to carry out on its own pose one of the most difficult challenges in energy-innovation policy. The newly established OCED will fill the most glaring gap in the United States' clean energy innovation system. ITIF's assessment of a portfolio of 53 energy technology demonstration projects managed by DOE's applied energy offices between 2009 and 2011 finds that the agency did not perform well on key criteria such as cost sharing, information sharing, and assessment of the follow-on environment.[45]

The new, standalone OCED, if staffed with managers with commercial project management and financial expertise, has a great opportunity to overcome these weaknesses.[46] In addition, it would

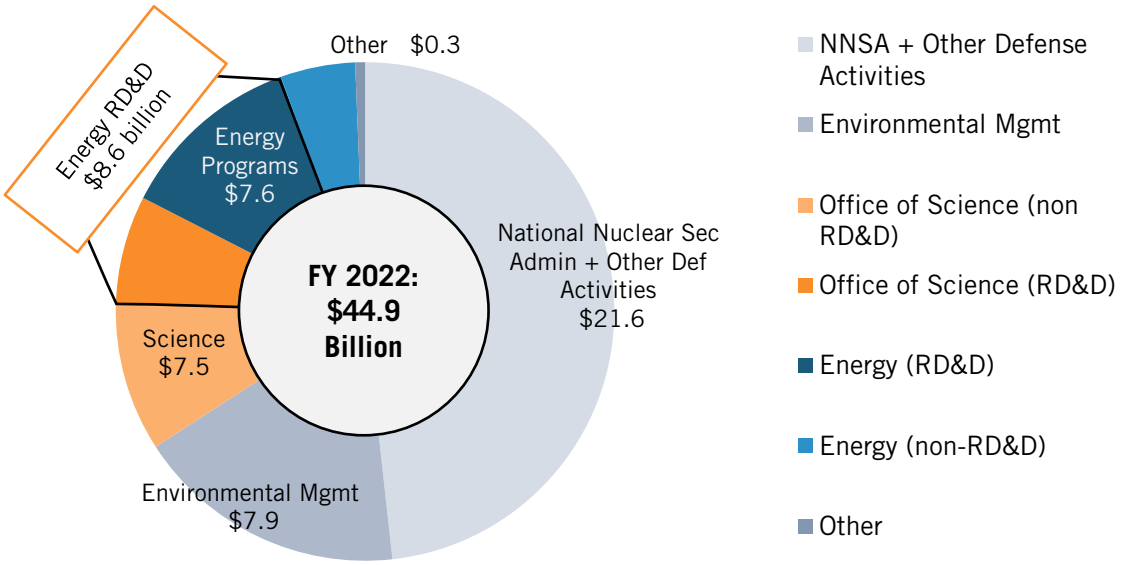
affirm the importance of demonstration as a vital and distinct step in the energy innovation process that is worthy of federal support.[47]

Yet, the IIJA's initial funding just begins to fill the need for investment in clean energy demonstrations. The act's appropriation for energy storage, advanced reactors, and carbon capture technologies—technologies both IEA and the most recent Intergovernmental Panel on Climate Change (IPCC) assessment report have identified as extremely important in fulfilling the Paris Agreement—will sunset after FY 2025; funding for other technology areas will end after FY 2026. A more sustained effort will be necessary to achieve national and global climate goals. As OCED builds its foundation and proves its value, its regular appropriations must grow to avert going off this "fiscal cliff" and stranding the nation's nascent large-scale energy demonstration program.[48]

THE DEPARTMENT OF ENERGY—AND LOTS OF OTHER STUFF

DOE oversees much more than the nation's energy system. Indeed, when the other activities of DOE—defense, environmental cleanup, and non-energy-focused basic science—are taken into account, only a small portion of its budget remains to support clean energy innovation. Figure 4 shows DOE's budget by organization. The department's $8.4 billion energy RD&D portfolio includes just a minority of the department's Office of Science (SC), along with most of the funding assigned to its varied applied energy offices.

Figure 4: FY 22 enacted DOE budget by major function ($44.9 billion)



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 almost half of the agency's nearly $45 billion budget. The next biggest function, DOE's

Office of Environmental Management (EM) is tasked with cleaning up the massive pollution left behind by the weapons program. It absorbs 18 percent of the budget. Together, these two slices make up two-thirds of the department's budget and contain no energy RD&D programs.

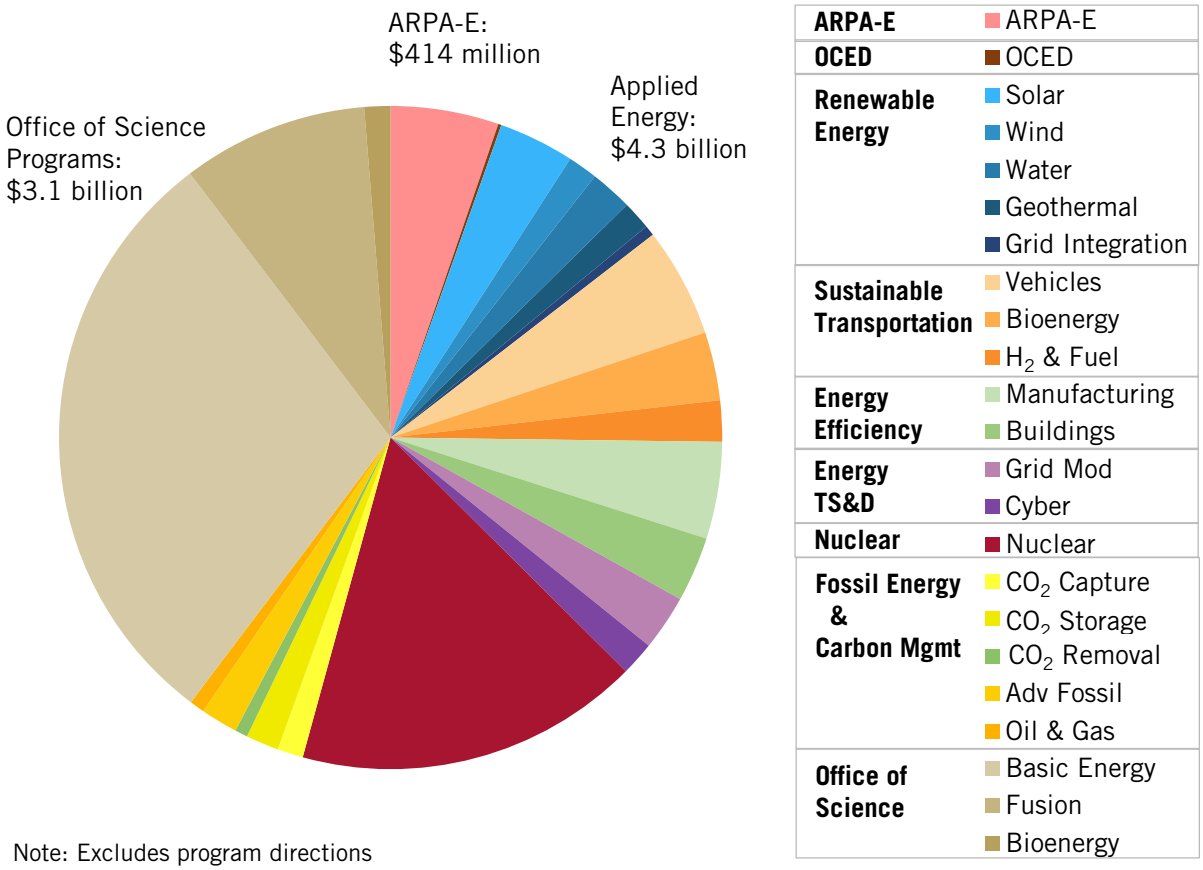
DOE's $7.5 billion SC is one of the government's largest funders of basic science research, providing critical research infrastructure through its support for 10 of DOE's 17 national laboratories. SC's research investment is spread across six program areas—Advanced Scientific Computing Research, Basic Energy Sciences (BES), Biological and Environmental Research (BER), Fusion Energy Sciences (FES), High Energy Physics, and Nuclear Physics—plus two new program areas: Isotope R&D and Production and Accelerator R&D and Production. 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 the applied energy offices: Energy Efficiency and Renewable Energy (EERE), 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 (FECM); and Nuclear Energy (NE). In addition, 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. The new OCED is housed in a new Office of Infrastructure and, as noted, supports clean energy technology demonstration projects.

DOE's energy programs also support non-RD&D functions. The Energy Information Administration, for instance, 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 finances energy infrastructure projects on tribal lands. 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.

DOE's entire energy RD&D portfolio totals $8.6 billion for fiscal year 2022, or about 19 percent of DOE's budget (figure 4.) The portfolio spans 23 science and technology program areas: ARPA-E, OCED, and across 7 technology categories (see figure 5): renewable energy; sustainable transportation; energy efficiency; energy transmission, storage, and distribution (TS&D); nuclear energy; fossil energy & carbon management; and basic energy-related research.

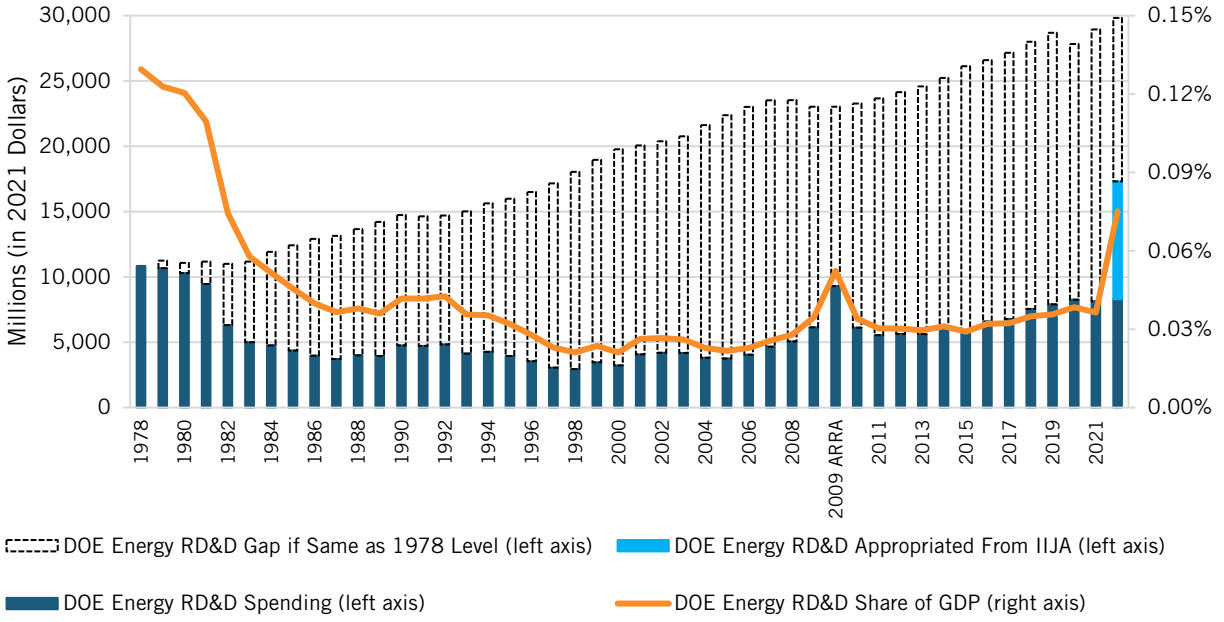
Figure 5: DOE's RD&D funding by program area, FY 2022



Note: Excludes program directions

The federal government has not always been so stingy. In 1978, Congress invested more than $10.8 billion (in 2021 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 $30 billion, on par with other national priorities such as health research.[49] The IIJA added $9.1 billion on top of the regular FY 2022 budget, bringing the total to $17 billion, a big jump but still $13 billion short of the 1978 benchmark (see figure 6.)

Figure 6: U.S. DOE RD&D spending, FY 1978 through FY 2022[50]



DOE RD&D: GENERATING ENVIRONMENTAL AND ECONOMIC BENEFITS

With a relatively small investment, federal energy RD&D has delivered big returns for the American public. DOE's investments have led to the commercialization of new products, lower costs and speedier deployment of clean technologies, energy savings for consumers and businesses, less pollution from dirty energy, and GHG 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.[51] An external review of energy efficiency and renewable energy RD&D at DOE finds 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.[52]

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 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).[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, although this project has not yet been fully financed or commenced construction.[54]

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 national 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 these analyses, 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, achieving a nationwide average of 6 cents per kilowatt-hour ($0.06/kWh), on par with natural gas baseload generation.[55] The initial SunShot target had been 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.[56] The department projected that achieving these goals could result in solar energy supplying 14 percent of U.S. electricity (up from 3 percent in 2021), support 290,000 new solar jobs, and translate into $30 billion in annual energy cost savings.[57] In March 2021, DOE announced that it was moving up its SunShot goal by five years, targeting $0.03/kWh by 2025, with a new target of $0.02/kWh by 2030.[58]

Other notable DOE technology targets include reducing:[59]

- 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;[60]
- the cost of batteries for EVs to $80/kWh, increasing their range to 300 miles and decreasing charging time to 15 minutes by 2028;[61]
- the cost of clean hydrogen by 80 percent to $1 per kilogram in one decade;[62]
- the cost of carbon capture to under $30 per metric ton, which could result in more than 150 million metric tons of CO_2sequestered by 2030;[63]
- the cost of CDR from the atmosphere to $100/ton of net CO_2-equivalent;[64] and
- fugitive emissions from natural gas systems by 40–45 percent, which would improve public safety, reduce GHG emissions, and ensure that more natural gas makes its way from the producer to the end customer.[65]

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 concludes that if its current RD&D programs were to meet their targets for reducing costs and improving performance of clean energy technologies, U.S. carbon emissions could fall 23 percent by 2040 and lower residential energy bills by 25 percent.[66] And if DOE doubled its RD&D budget, U.S. emissions would fall 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.[67]

Because of its ability to both reduce carbon emissions and lower energy bills, expanding public investment in RD&D may be more palatable to policymakers than would be 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 for climate policy that would otherwise be prohibitively expensive or politically untenable.

2022: MAINTAINING THE MOMENTUM FOR 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 September 2021 poll finds that 81 percent of registered voters support funding more research into clean energy sources such as solar and wind power.[68] Lawmakers from diverse backgrounds have embraced energy innovation as a strategy to combat climate change and promote U.S. competitiveness. Since 2011, Congress has increased federal funding for energy RD&D (inflation-adjusted) in every single year except 2015 and 2021. Furthermore, Democrats and Republicans have joined forces to advance legislation to accelerate innovation in technologies as diverse as energy storage, advanced renewables, carbon capture, and nuclear power.

Reflecting this bipartisan consensus, the Energy Act of 2020 provided a sweeping overhaul of DOE's programs and the first major reauthorization in more than a decade. It created new programs to address technology gaps, expanded programs to scale up and commercialize technologies developed in DOE's national labs, and authorized significant boosts in funding. Congress doubled down on energy innovation by passing the IIJA in 2021. The IIJA funds clean hydrogen, CCS, and EV batteries, which are key to tackling emissions in hard-to-abate sectors, at unprecedented levels. It also established the Office of Clean Energy Demonstration, filling a glaring gap in DOE's portfolio.

Internationally, the Biden administration has recommitted the United States to the Paris Agreement. Although the Trump administration had withdrawn from the agreement, key GOP lawmakers took an active part in the Glasgow climate summit in 2021, which reviewed progress toward the Paris goals.[69] The United States' renewed leadership is also expressed in its effort to reconfigure the Mission Innovation initiative that was signed alongside the climate agreement in Paris (box 4).

Box 4: Mission Innovation 2.0: Better and More?

As part of Mission Innovation (MI)—an international agreement launched in 2015 in tandem with the Paris Agreement to accelerate clean energy innovation—the United States committed to doubling public investment in clean energy RD&D by 2021. Although the United States did not quite meet this ambitious goal that year, the boost in spending provided by the IIJA means the FY 2022 energy RD&D budget is almost triple that of FY 2015.

Collectively, the 24 original members of MI fell some $50 billion short of the five-year doubling goal.[70] MI 2.0 began in 2021 with a promise to do better and more via a series of new missions such as clean hydrogen, net-zero industries, and zero-emission shipping.[71] The United States is spearheading several thrusts within MI 2.0, for example, partnering with the World Economic Forum in introducing the First Mover Coalition, which aims to spur innovation in emergent technologies that help decarbonize aviation, shipping, trucking, steel, aluminum, concrete, chemicals, and CDR.[72] The United States also co-leads the Zero-Emissions Shipping Mission with Denmark and Norway and the Clean Hydrogen Mission with Australia, Chile, the European Union, and the United Kingdom.

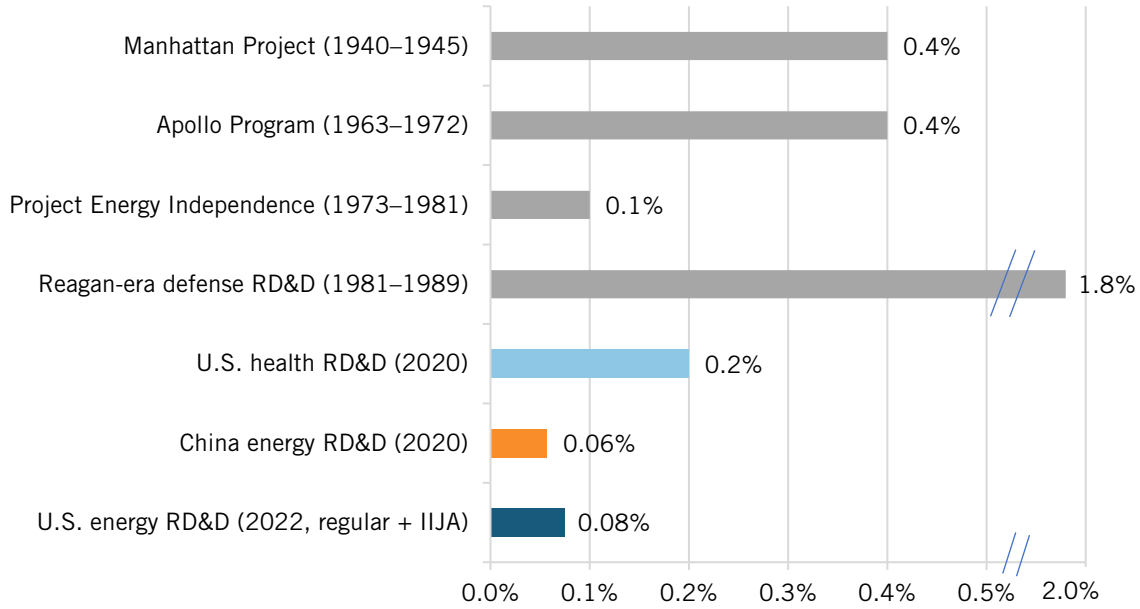
2023: TAKING THE NEXT STEP

These actions and achievements signal that the United States has now moved on from playing catch-up into a new era of further energizing innovation. The successful passage of the Energy Act of 2020 and the IIJA of 2021 positions Congress to aim for new levels of ambition. And a growing chorus of science and technology policy experts, in addition to the authors of *Energizing America*, are backing this call.

For instance, 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 investments.[73] 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 have endorsed this target.[74] Other organizations have called for even more ambitious increases. The Environmental Defense Fund set a goal of $32 billion by FY 2025.[75] Breakthrough Energy suggests $35 billion by 2030.

These targets for federal energy RD&D spending are all roughly 0.1 percent of GDP.[76] 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 7). Federal investment in RD&D has accelerated the development of life-saving drugs, modernized the military's arsenal, and even put a man on the moon. Clean energy deserves similar investment.

Figure 7. Federal RD&D funding as a percentage of GDP for selected national innovation missions[77]



President Biden's Budget Request for FY 2023

In March 2022, the Office of Management and Budget released the outline of President Biden's budget request for FY 2023, which calls for a 32 percent increase in government-wide investment in clean energy innovation over FY 2021-enacted levels.[78] (FY 2022 levels had not yet been set when the administration prepared its request.) Highlights include:

- $48.2 billion for DOE, a $3.3 billion (8 percent) increase over FY 2022;
- $11.9 billion for clean energy innovation programs government-wide, a $1 billion increase compared with the FY 2022 request, of which $9.4 billion would go to DOE's applied energy offices, SC, and ARPA-E;
- $7.8 billion for DOE's SC, including $3.2 billion that would support climate-tech and clean energy research;
- $700 million for ARPA-E, including expanded authority for ARPA-E to more fully address innovation gaps around adaptation, mitigation, and resilience to the impacts of climate change;
- the Secretarial crosscuts, which are continuous major multi-office initiatives in the following areas: Advanced manufacturing, biotechnology, CDR, critical minerals and materials, cybersecurity, energy storage, energy-water nexus, grid modernization, hydrogen, and industrial decarbonization; and
- $2.1 billion for the new Office of Infrastructure, overseen by a new undersecretary, which brings together specialized capabilities for managing large-scale demonstration, commercialization, and deployment programs.

Table 1 provides a top-level summary of DOE's budget, and table 2 provides a summary of DOE's RD&D programs.

Table 1: DOE budget by program area, FY 2020 enacted through FY 2023 request, in millions of dollars

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Enacted	FY 2023 WH Request
DOE Total Budget	38,657	41,927	44,856	48,184
Defense*	17,611	20,608	21,641	22,389
Environmental Management**	7,425	7,586	7,904	8,060
Office of Science, non-Energy RD&D	3,937	3,927	4,270	4,570
Office of Science, Energy RD&D	3,063	3,099	3,205	3,229
EERE, FECM, NE, OE, and CESER, non-Energy RD&D	821	864	1,236	501
EERE, FECM, NE, OE, and CESER, Energy RD&D	4,558	4,623	4,907	6,585
ARPA-E	425	427	450	700
OCED	--	--	20	214
DOE Energy RD&D Programs*	8,046	8,149	8,582	10,728

* NNSA and Other Defense Activities.

** Defense Environmental Cleanup, Non-Defense Environmental Cleanup, and Uranium Enrichment Decontamination and Decommissioning.

Table 2: DOE Energy RD&D programs summary, FY 2020 enacted through FY 2023 request, in millions of dollars

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Enacted	FY 2023 WH Request
DOE Energy RD&D Programs*	8,046	8,149	8,582	10,728
ARPA-E	425	427	450	700
Energy Efficiency & Renewable Energy	2,228	2,282	2,466	3,867
Sustainable Transportation				
Vehicle Technologies**	396	400	420	603
Bioenergy Technologies	260	255	262	340
Hydrogen & Fuel Cell Tech**	150	150	158	186
Renewable Energy				
Solar Energy**	280	280	290	535
Wind Energy**	104	110	114	345
Water Power**	148	150	162	191
Geothermal Technology**	110	106	110	202
Renewable Energy Grid Integration**			40	58
Energy Efficiency				
Advanced Manufacturing**	350	351	371	528
Building Technologies**	230	235	250	317
Program Support	201	245	291	563
Fossil Energy and Carbon Management R&D	713	684	646	801
Carbon Management Technologies	511	447	416	474
Natural Gas Technologies	51	57	--	--
Resource Sustainability			95	183
Unconventional Oil Tech	46	46	--	--
NETL Research	50	83	83	83
Program Support	55	51	52	61
Nuclear Energy	1,331	1,350	1,389	1,510
Reactor Concepts RD&D	267	208	257	135
Nuclear Energy Enabling Tech	113	123	117	103
Fuel Cycle R&D	305	309	320	422
Advanced Reactor Demos	230	250	250	230
Versatile Test Reactor***	--	45	--	45
Other Programs	345	348	378	498
Program Support	71	67	67	77
Electricity	182	203	265	266
Cybersecurity (CESER)	104	104	142	143
Science	3,063	3,099	3,205	3,229
Basic Energy Sciences	2,213	2,245	2,308	2,420
Fusion Energy Sciences	671	672	713	723
BER Bioenergy Research Centers****	100	100	100	--
Program Support	79	82	84	85
Office of Clean Energy Demonstration	--	--	20	214

* Energy programs include some non-RD&D functions, only those pertaining to RD&D functions are listed here.
** The FY 23 budget requests in the OMB version differ from DOE's Budget Justification. Amounts are based on the DOE's version.
*** The Versatile Test Reactor was previously funded in FY 2018 and FY 2019 out of the Reactor Concepts RD&D subprogram.
**** The BRCs will undergo a merit review for a possible five-year renewal in FY 2022 upon successful outcome of the review.

Gaps in the Proposed Budget and Longer-Term Challenges

Of course, some gaps remain in the federal clean energy portfolio. Although IIJA funding and the requested budget would carry several programs well beyond the levels recommended in *Energizing America* for FY 22 and FY 23 (figure 8), support for building, bioenergy, and geothermal technologies has lagged behind (see box 5.)

Figure 8: FY 2022 enacted and FY 2023 proposed appropriations plus IIJA relative to Energizing America recommendations

Figure 7 also points to a longer-run problem. IIJA funding is nominally flat over its five-year horizon, whereas *Energizing America* recommends a gradual ramp up. As a result, funding for some offices will decline in FY 23 relative to EA's recommendations—a trend that will continue in FY 24 and beyond unless regular appropriations for energy RD&D rise faster than their historic trend. The problem will become even more difficult when IIJA sunsets after FY 26.

Box 5: Building, Bioenergy, and Geothermal—Underappreciated Offices

The IIJA appropriated over $40 billion in clean energy RD&D investment from FY 2022 to FY 2026. Unfortunately, the Building Technologies Office (BTO), the Bioenergy Technologies Office (BETO), and the Geothermal Office (GTO) were overlooked, even though these offices may play crucial roles in decarbonizing the U.S. economy.

BTO develops, demonstrates, and accelerates the adoption of cost-effective technologies, techniques, tools, and services in residential and commercial buildings. Its past successes include energy-efficient water heaters, solid-state lighting, and energy-saving windows. A retrospective assessment of a major portion of BTO investments between 1976 and 2015 yields a benefit-to-cost ratio of between 20:1 and 66:1.[79] The residential and commercial sectors collectively comprised 13 percent of GHG emissions in 2019 while BTO regularly receives just 3

percent of DOE's RD&D budget.[80] GHG emissions from these sectors have risen relative to 2005, even as total GHG emissions are declining.

BETO, which also receives 3 percent of DOE's RD&D budget, supports RD&D to enable the sustainable use of domestic biomass and waste resources for the production of biofuels and bioproducts. These products may contribute to decarbonizing hard-to-abate sectors such as aviation and industry. The world's first commercial flight using sustainable aviation fuel from recycled waste carbon gases in 2018 resulted from BETO-supported advances in renewable fuels and bioproducts.[81]

GTO supports renewable energy technologies, with the potential to provide power around the clock and in all seasons. Geothermal power is not intermittent (as solar and wind are) or weather dependent (like hydro is). DOE's GeoVision report highlights its potential to reach over 60 GW of capacity by 2050, which could translate to 8.5 percent of total electricity generation.[82] Integrating geothermal technologies with other technologies such as heat pumps and district heating could yield results across multiple sectors. Although the IIJA is providing $21 million each year from FY 2022 to FY 2025, GTO has consistently received less funding than the other three renewable energy offices do.

Additional RD&D investments in building, bioenergy, and geothermal technologies could bring large rewards. As the United States charges full speed toward a net-zero-emissions economy in 2050, it should not neglect these opportunities.

OTHER LEGISLATIVE OPPORTUNITIES

The administration's FY 2023 budget proposal is not the only pending legislation with the potential to impact the federal RD&D portfolio. Congress could also move the reconciliation package currently labeled "Build a Better America" and an innovation and competitiveness bill that blends the Senate's U.S. Innovation and Competitiveness Act (USICA; S.1260) and the House's America COMPETES (Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science) Act (H.R.4521).

Build a Better America

New legislation, provisionally titled "Build a Better America," is likely to include elements of the Build Back Better Act (BBBA; H.R.5376). The BBBA calls for a federal investment of $555 billion toward building a clean energy economy, including investments in RD&D and manufacturing.[83] While the vast majority of this sum would be devoted to tax incentives and other provisions that could impact innovation through accelerated deployment, it also includes the following spending provisions:[84]

- $1 billion for EERE to carry out advanced demonstration projects on building, renewable energy, bioenergy, and vehicle technologies
- $885 million for fusion energy R&D in SC
- $10 million for FECM-funded demonstration projects that would reduce the environmental impacts of produced water

The BBBA passed the House and is currently being revised in negotiations with the Senate and the White House.

Innovation and Competitiveness Legislation

Both chambers of Congress have passed competitiveness bills that would reshape major features of the U.S. innovation system. This rare convergence presents a big opportunity if the conference committee can resolve the differences between them.[85] Both bills would establish a Foundation for Energy Security and Innovation, a nonprofit entity with a mission to support DOE.[86]

Other key climate and energy innovation provisions being considered by the conferees include:[87]

- $16.9 billion to carry out R&D and address energy-related supply chain activities within the key technology focus areas, gradually ramping up from $1 billion in FY 2022 to $5.5 billion in FY 2026;
- an interagency committee including DOE that would conduct and support RD&D and commercial application activities in engineering biology; and
- support for the development, optimization, and validation of novel, scalable tools and technologies to enable the dynamic study of molecular processes in situ.

Both chambers of Congress are currently resolving the differences between the bills, with more details about how the proposal would impact DOE's energy RD&D budget likely to emerge soon.

WHAT HAPPENS NEXT

The next step in the budget process after the president's proposal is offered is for congressional leaders to agree on the top line of the defense and nondefense discretionary budgets. The appropriations committees must then apportion this total 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 DOE RD&D funding will be limited by the E&W 302(b) allocations.[88]

All appropriations are supposed to pass both chambers of Congress and be signed by the president before the next fiscal year begins on October 1. However, continuing resolutions that extend current fiscal-year spending levels into the next fiscal year is a tactic that has been used frequently in recent years, and many observers expect this pattern to continue this year.

Concurrent with the appropriations process, Congress's authorizing committees are picking up where the Energy Act of 2020 and the IIJA left off. The House Committee on Science, for instance, held hearings on bioenergy technologies, clean hydrogen, and the supply of EV batteries and critical minerals in 2022.[89] The Senate Committee on Energy and Natural Resources also held hearings on clean hydrogen and critical minerals as well as hydropower.[90] The House Committee on Energy and Commerce conducted a wide-ranging hearing with DOE Secretary Granholm on the FY 23 budget request for DOE.[91] While these hearings may not impact the FY 2023 budget directly, they could lead to new legislation that would 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. In spite of the global coronavirus crisis and supply chain challenges, the United States should lead the response to climate change and prosper as the world transitions to clean energy. Congress should seize the opportunity offered by the FY 2023 budget to build on the foundations laid by the Energy Act of 2020 and the IIJA and continue to elevate energy innovation as a national priority.

Acknowledgments

The authors wish to thank Colin Cunliff and Linh Nguyen for their work on prior editions of this report. Any errors or omissions are the authors' alone.

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