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U.S. Federal Scientific Research and Development: Budget Overview and Outlook

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The Biden administration has made science and technology (S&T) a centerpiece of its early policy agenda, which includes ambitious targets for federal investments in research and development (R&D). In parallel, growing concerns among some members in Congress about U.S. global leadership in S&T-focused industries, especially in relation to China, have inspired a number of recent legislative efforts to strengthen the national innovation ecosystem. While President Biden's first budget proposal works to build on this momentum in an effort to authorize historic increases to federal R&D agencies, challenges remain to ensure long-term, international competitiveness across scientific disciplines and advanced technologies. In this paper, we describe the U.S. federal budget process for R&D, discuss trends in federal R&D funding, and provide an outlook for the future of federal R&D expenditures during the Biden administration.

THE ROLE AND VALUE OF FEDERAL S&T R&D

Scientific R&D is essential to creating new knowledge and tools, which in turn spur the development of new products and technologies that drive the domestic and global economies.[1] Although difficult to quantify, economists cite "strongly positive" private returns on investments in R&D and estimate that innovations stemming from S&T account for more than 60% of economic growth over the last century.[2]

U.S. R&D involves a complex system of actors: individuals and institutions that perform R&D, federal and state agencies that regulate R&D, and funders, both public and private, who support R&D activities. In fiscal year (FY) 2019, the U.S. spent more than $656 billion on R&D, equivalent to 3.06% of the U.S. gross domestic product (GDP).[3] This money sponsors hundreds of thousands of S&T research projects across R&D sectors—colleges and universities, research hospitals, private industry, national laboratories, and other federally funded research and development centers (FFRDCs) (e.g., the RAND Corporation), as well as other independent organizations who participate in or manage research activities.

More than two-thirds of U.S. R&D is funded by private corporations, approximately 20% is funded by the federal government, and the remaining share is sponsored by nonprofit organizations, state governments, and universities. The nature of R&D varies between federally funded and industry-sponsored R&D. Industry focuses primarily on the development of new products (Figure 1). It accounts for 85% of the U.S. development total. In contrast, federal spending favors

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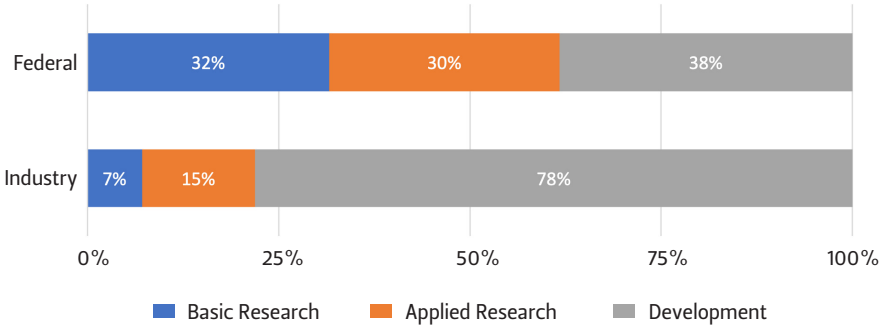
FIGURE 1 — U.S. R&D BY SECTOR AND CHARACTER, FY 2019.



NOTE Industry-sponsored research primarily supports development activities, whereas federal R&D is allocated evenly by character.
SOURCE NSF, National Patterns of R&D Resources: 2018–19 Data Update, NSF 21-325.

Shifting priories between presidential administrations, changes to the makeup and ideology of Congress, and broader economic conditions in the United States at large have resulted in inconsistent funding for R&D.

research—both "basic" research, which is conducted without a targeted outcome, and "applied" research, which seeks to advance knowledge toward a predetermined goal.[4]

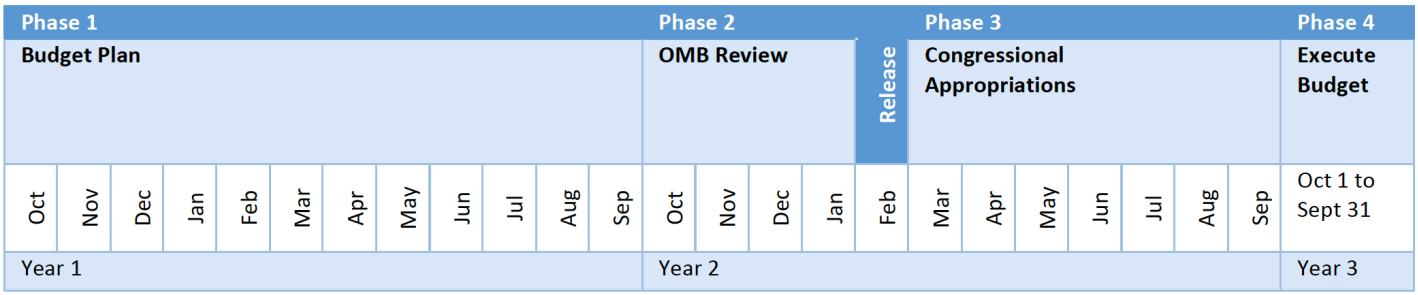
Traditionally, federal funding for R&D receives bipartisan support in Congress, particularly for health- and defense-related research activities. However, since the mid-1990s, government spending on basic research has declined or stagnated as a share of the U.S. GDP, in part due to the intrinsic uncertainties about the ultimate impacts of basic research. In addition, certain areas of S&T R&D have become increasingly politicized, including climate research and research using human embryos. Moreover, academic scientists historically do not participate in advocacy for increases to federal R&D funding. Relatively little value has been placed on evaluating and communicating the broader societal impacts of basic research to the public and especially to policymakers.[5] As the high technology sector (e.g., advanced computing and communications, social media platforms, and other web-based services) becomes an increasingly large part of the overall U.S. economy, federal funding for early stage R&D, which has been at the root of much of the technological progress of this past century, is more important than ever.[6] The emergence of the COVID-19 pandemic in 2020, its spread in the United States, and the record-setting development of effective vaccines reinforces the need for a robust R&D infrastructure. This infrastructure requires sustained investment in basic research to increase our fundamental understanding of infectious diseases, as well as the ability to respond to and manage future global crises.[7]

THE U.S. FEDERAL BUDGET PROCESS FOR S&T R&D

The total U.S. annual federal budget is more than $4.8 trillion. There are three major funding categories in the budget: 1) the interest on the national debt ($378 billion in FY 2021, 8% of the total budget); 2) nondiscretionary or mandatory spending, which includes Social Security, Medicare, and Medicaid ($2.97 trillion in FY 2021, 62% of the total budget); and 3) discretionary spending. Mandatory spending and interest on the debt are non-negotiable expenses. Discretionary spending encompasses all other government spending, from transportation to military operations ($1.49 trillion in FY 2021, 31% of the total budget), including the entire federal R&D budget.[8] As a result, discretionary spending—less than a third of total federal expenditures—is the only part of the budget that is publicly debated each year between the two houses of Congress and the president.

S&T is just one of many policy areas vying for public funding. Federal funding for S&T is also complicated not just by the political nature of the U.S. budget process, but by the highly decentralized organization of federal R&D activities—over a dozen federal agencies have an annual R&D budget of more than $1 billion. In Congress, these activities are managed and funded across numerous congressional oversight and appropriations committees without a central mechanism to coordinate related federal R&D programs. This pluralism results in a complex, often contentious, multi-year process characterized by a series of lengthy negotiations between Congress, the White House, and R&D granting and regulatory agencies and cabinet departments, all of which are responding to conflicting expectations and demands (Figure 2). Shifting priorities between presidential administrations, changes to the makeup

FIGURE 2 — U.S. FEDERAL BUDGET PROCESS.



NOTE The federal budget process is conducted in four phases over three years from agency planning through the execution of the budget.
SOURCE Adapted from American Association for the Advancement of Science.

and ideologies of Congress, and broader economic conditions in the United States at large have resulted in the inconsistent funding for R&D, especially for basic research, despite strong and consistent support from the American public.[9]

The annual budget funds government operations for the U.S. fiscal year, which begins October 1 and ends September 30 the following year (i.e., the FY 2022 budget will start October 1, 2021 and end September 30, 2022). However, the entire budget process is a multi-year endeavor that starts two years prior to funds being released. The process has four phases (Figure 2):

1) Budget Plan: Initial internal planning within cabinet departments and agencies

2) White House Review: White House Office of Management and Budget (OMB) review of each department and agency's budget and subsequent negotiations between agencies and OMB to finalize the president's budget request to Congress

3) Congressional Appropriation: Submission of the president's budget to Congress, followed by negotiations in Congress and between Congress and the president, resulting in the passage of the full public budget into federal law

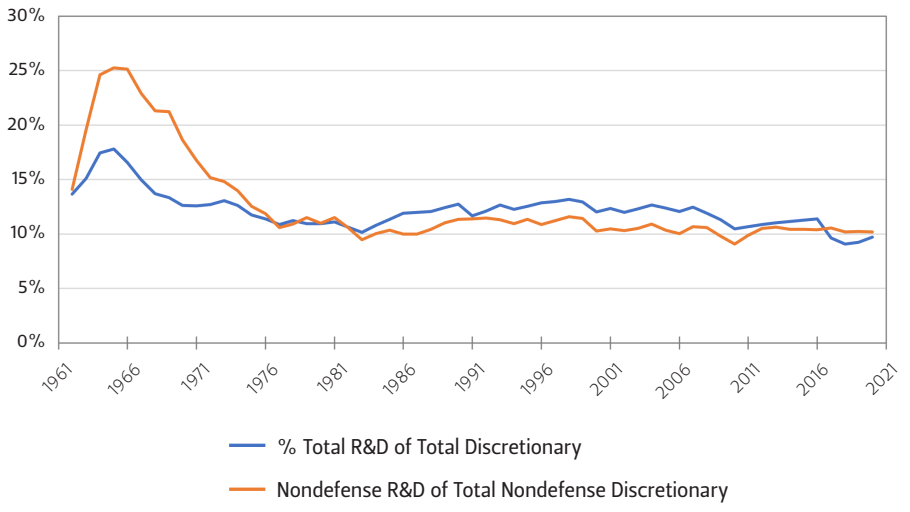
4) Budget Implementation: Appropriated funds are distributed

The first phase of the budget process consists of internal, nonpublic planning of budget proposals within the cabinet departments and independent agencies beginning up to two years prior to the start of the fiscal year. In parallel, the president develops government-wide priorities for federal departments and agencies. For agencies involved with R&D funding and regulation, the president's S&T priorities are detailed in a joint memorandum co-signed by the directors of OMB and the Office of Science and Technology Policy (OSTP), an agency within the White House that works to coordinate the expansive federal R&D system, including budgets and interagency R&D programs and activities.[10] Agencies and departments are expected to take into consideration the president's priorities, including the OMB-OSTP budget memo, when planning their budgets for their activities for a given fiscal year.

During the second phase, agencies send their preliminary budgets to OMB, initiating a series of negotiations between OMB and each agency that are often called "passbacks." The result of these negotiations becomes the president's budget request to Congress, typically submitted in mid-February. While the Budget and Accounting Act of 1921 requires a submission to Congress by the first Monday in February, the budget can be delayed until later in the spring, which is often the case during presidential transitions.

The United States, in contrast to many other countries, has no central mechanism to coordinate annual R&D budgets across the federal government or assess the nation's overall progress in S&T.

FIGURE 3 — FEDERAL R&D AS A PERCENT OF DISCRETIONARY SPENDING, 1962–2020.



NOTE Since its peak in the 1960s, due to the Apollo program, total federal R&D spending has been consistently 10%–12% percent of the overall discretionary budget (light blue). Federal nondefense R&D spending has followed a similar trend in comparison to the total nondefense discretionary budget (orange).
SOURCE Adapted from the American Association for the Advancement of Science 2021.

In the third phase, Congress reviews the presidential budget proposal and determines the final budget. The House and Senate appropriations committees divide the total discretionary budget across 12 appropriations subcommittees in their respective chambers. Each subcommittee prepares a funding bill covering the agencies under its jurisdiction.[11] In early April, the House and Senate typically agree on a "budget resolution," which provides nonbinding guidance to the appropriations subcommittees on national budget priorities. From FY 2011 to FY 2021, the budget resolution also addressed top-line funding levels for defense and nondefense discretionary budgets, or "caps," as set and later amended by the Budget Control Act of 2011 (S. 365) in a response to the 2011 debt-ceiling crisis. However, over the past decade Congress has raised the caps on several occasions through new legislation to increase the available pool of funds for discretionary programs and avoid budget cuts across the government.

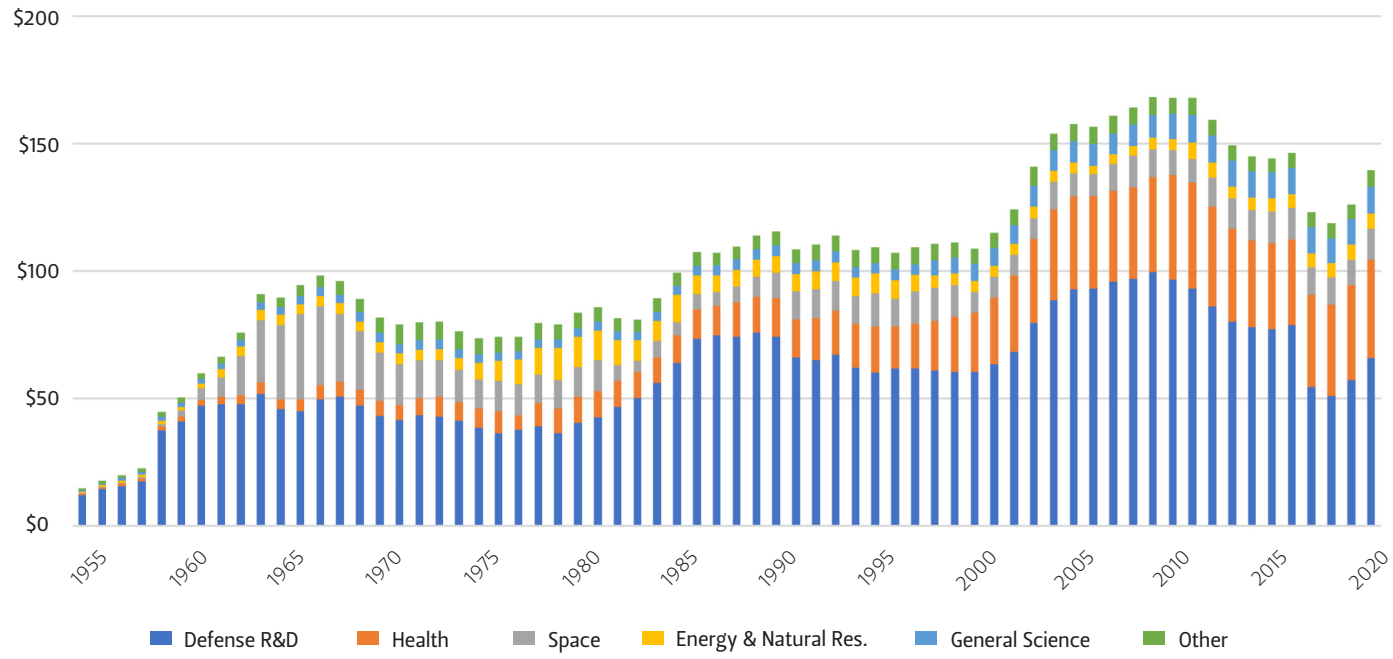
The size of these caps are incredibly important to the future of federal R&D, as the overall federal R&D budget has been proportional to total discretionary spending since the late 1970s. Over the past 40 years, federal R&D has accounted for approximately 12% of the total discretionary budget, irrespective of broader national policy priorities, the makeup of Congress or the president's political party, the state of the national economy, wars, crises, or any other historical context (Figure 3).[12]

Defense spending has always been the largest portion of the R&D budget (Figure 4). However, the balance of funding between nondefense S&T disciplines (space, engineering, physical sciences, health and medicine, etc.) has shifted considerably with time. For example, in the 1960s a large portion of R&D funding was allocated to the Apollo program and space-related R&D. In contrast, since the early 2000s, almost half of nondefense spending has been focused on health and biomedical research.

The United States, in contrast to many other countries, has no central mechanism to coordinate annual R&D budgets across the federal government or assess the nation's overall progress in S&T. OSTP is the only federal agency that works to coordinate the nation's overall S&T enterprise and national R&D programs.[13] However, OSTP's role in the funding process is, by statute, purely advisory, and it does not have funding authority for federal R&D activities. Large interagency R&D programs (e.g., the National Nanotechnology Initiative) are coordinated by the National Science and Technology Council (NSTC), a cabinet-level committee managed by OSTP and chaired by the president that works to harmonize policy, including budgets, across the many agencies involved in S&T. However, funding for individual agency R&D budget requests are set by the agencies according to their mission priorities and subsequent negotiations in Congress.

This disaggregated system of appropriations means that most R&D agencies do not compete directly with one another for funds, but rather with nonscience programs, many of which are popular with the public and special interest groups. Out of the 12 appropriations bills, budgets for R&D granting or regulatory agencies are dispersed across nine separate appropriation subcommittees. For

FIGURE 4 — FEDERAL R&D FUNDING BY FUNCTION, 1955–2020 (IN BILLIONS OF CONSTANT FY 2020 USD).



NOTE U.S. federal funding over time lacks consistency, with times of growth, plateaus, and declines over the past 70 years, reflecting changing priorities in Congress and the White House.
SOURCE Adapted from the American Association for the Advancement of Science 2021.

example, the National Science Foundation (NSF) and National Aeronautics and Space Administration (NASA) are in the same appropriations bill as the Departments of Commerce and Justice. The Department of Energy (DOE) is appropriated through a bill that includes energy and water development projects. The National Institutes of Health (NIH), which resides in the Department of Health and Human Services (DHHS), is included on a bill with the Departments of Education and Labor. These congressional subcommittees wield considerable power over the operations of the agencies. If, at any time during budget negotiations, an agency wishes to deviate from the original budget, even to move relatively small amounts of money from one activity to another, it must obtain approvals from OMB and the relevant subcommittees in both the House and Senate before proceeding.

The Senate and House must agree on the final funding bills and send them to the president to be signed into law before the start of the following fiscal year on October 1. Unless an agency "has an appropriation" (i.e., the bill including its funding has been signed into law), by the end of a fiscal year, it cannot spend money and must cease operations, except for a small number of specified essential services. For example, during the FY 2019 budget cycle, Congress and the president failed to pass an appropriation bill for the majority of agencies and departments, which resulted in a government shutdown for 35 days from December 22, 2018 to January 25, 2019.

Since the late 1970s, only on a few occasions has the complete federal budget been approved in time for the start of the fiscal year. Delays typically occur due to partisan discord within Congress or between Congress and the president, such as the fight between President Trump and the House Democrats in FY 2019 over border wall funding. If Congress is unable to pass all 12 appropriation bills by the deadline, it must enact one or several consecutive continuing resolutions that extend the deadline for negotiations into the start of the new fiscal year. In order to avoid a chain of continuing resolutions, Congress will often bundle the

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unresolved budget requests together as a single piece of legislation, known as an omnibus appropriations bill. Omnibus bills, which are becoming progressively more common, tend to contain a diverse set of unrelated legislative items. In FY 2020, for example, the federal budget was passed in December 2019 in two omnibus bills after a continuing resolution was signed by President Trump an hour before the October 1 deadline.

Delayed budget approvals can severely disrupt agency operations, with agencies forced to continue to work under the guidelines of their previous budgets with no way of knowing when their budget will be approved or what it will look like. Programs that a new fiscal budget would end or substantially alter still have funding for this period, while new projects cannot be started until the budget is approved. This system is particularly detrimental to R&D agencies, which need predictable budgets to ensure the continuity of data collection for long-term research programs, as well as adequate staffing of research laboratories with scientists at all stages of their careers.[14] Graduate students and postdocs in training are particularly sensitive to gaps in access to research facilities or abrupt changes to career trajectories due to loss of federal funding.[15] Additionally, the construction of large-scale research facilities, such as telescopes, satellites, and particle accelerators, can span a decade or more, and relies on consistent funding to make predictable progress to meet program goals.

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After the president has signed each agency's appropriation bill into law, its legislatively mandated funds, or "obligations," are spent over the course of the following fiscal year—the fourth and final stage of the budget process. The agencies report expenditures back to the government to get the final totals for the budget spent, or "outlays," which typically fall within several percent of an agency's allotted obligations. By the time agencies are spending their annual appropriations, they are already well into negotiating the following fiscal year and setting priorities for the year after.

R&D FUNDING DURING THE TRUMP ADMINISTRATION

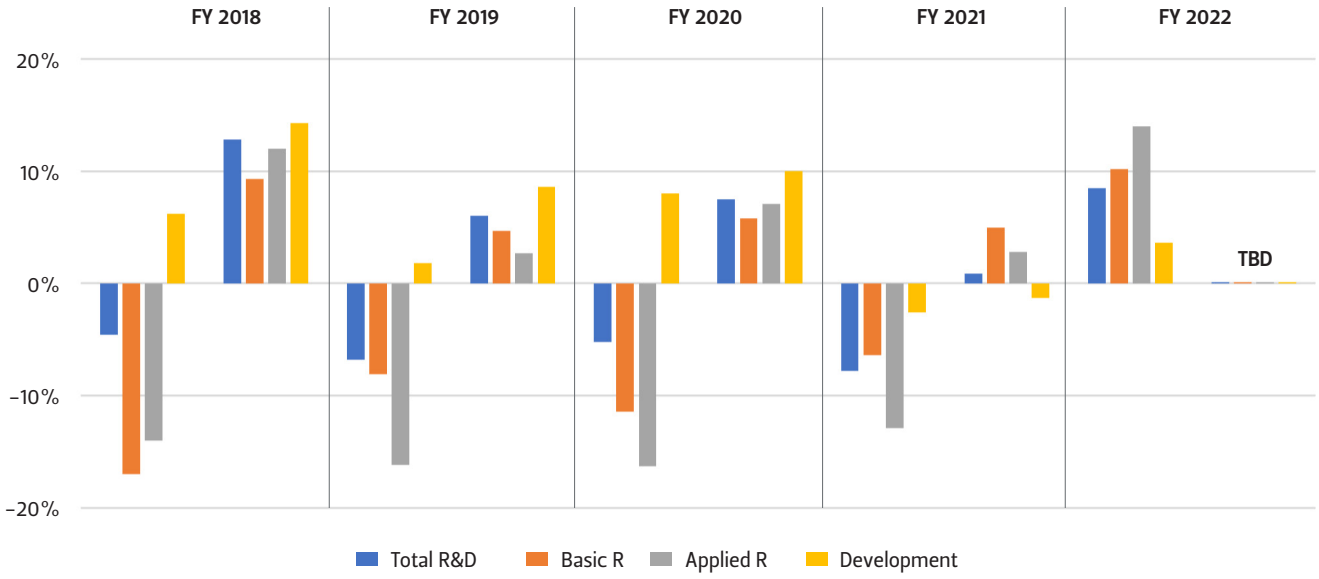
President Trump campaigned on increased defense spending and decreased nondefense discretionary spending, including many areas of S&T R&D.[16] Each of President Trump's four annual budget requests to Congress reflected these overall priorities, and called for cuts in spending across R&D funding and regulatory agencies (Figure 5). For example, in FY 2020, President Trump requested an 8% reduction to federal R&D programs from the appropriated FY 2018 total—from roughly $164 billion to $151 billion.[17] In addition, discretionary budget caps to limit deficit spending would have required large budget cuts for all discretionary programs, which if enacted would have had a devastating impact on federal R&D.

Fortunately, Congress largely ignored President Trump's budget proposals, and, in parallel, raised the discretionary budget caps in favor of more generous funding for R&D. Both Democrats and Republicans in Congress criticized the Trump administration's requests, taking issue with the president's proposed cuts to R&D programs—especially to energy research and demonstration programs at the DOE, including his proposal to outright abolish the DOE Advanced Research Projects Agency-Energy (ARPA-E), an agency which has had bipartisan support since its founding in 2009.[18]

President Trump's final budget proposal, released on February 10, 2020 and passed on December 27, 2020, followed his previous requests. His plan once again called for sharp reductions to basic and applied research expenditures—8.4%, or $13.2 billion, from FY 2020 levels. However, Congress appropriated modest increases roughly in line with discretionary budget caps, including a 3% increase to NIH, 2.5% for NSF, and 0.4% for the DOE Office of Science.[19]

In addition to these annual increases, federal R&D received short-term boosts in five of the six COVID-19 emergency relief bills passed over the past two fiscal years. The first such package, The Coronavirus

FIGURE 5 — CHANGE IN R&D BUDGET REQUEST AND APPROPRIATION FROM PREVIOUS FISCAL YEAR.



NOTE While President Trump called for reductions to federal basic and applied research funding (light) for FY 2018–FY 2021, congressional appropriations funded R&D agencies and activities more generously (dark). President Biden's first budget proposal requested increases to R&D for the upcoming FY 2022. FY 2021 data does not include COVID-19 relief appropriations.
SOURCE American Association for the Advancement of Sciences Interactive Dashboards, 2021.

Preparedness and Response Supplemental Appropriations Act (H.R. 6074), was passed on March 5, 2020. It allocated $8.3 billion to "prevent, prepare for, and respond to" the COVID-19 pandemic, with approximately $6.5 billion directed to agencies under the Department of Health and Human Services (HHS), including NIH, the Centers for Disease Control and Prevention (CDC), and the Biomedical Advance Research and Development Authority (BARDA). Passed on March 27, 2020, the $2.2 trillion stimulus package titled the Coronavirus Aid, Relief, and Economic Security (CARES) Act (H.R. 748) included $1.25 billion to support R&D.[20] The latest pandemic stimulus package, signed into law by President Joe Biden on March 11, 2021 and titled The American Rescue Plan of 2021 (H.R. 1319), added another significant one-time increase to select R&D agencies, including $600 million to NSF and $150 million to the National Institute of Standards and Technology (NIST).[21] Overall, BARDA and the CDC have each received more than $25 billion in stimulus funding so far, and NIH and NSF have received $5 billion and $676 million respectively (Figure 6).[22]

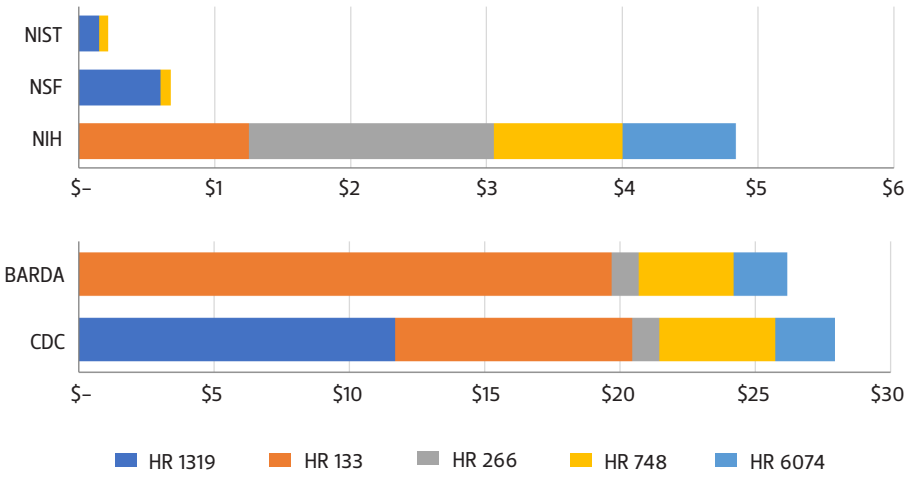
THE FUTURE OF FEDERAL R&D FUNDING

On April 28, 2021, President Biden, in his first address to Congress, highlighted S&T as part of his broader policy approach toward maintaining U.S. economic and national security:

"We will see more technological change in the next 10 years than we saw in the last 50 years. And we're falling behind in that competition. Decades ago we used to invest 2% of our GDP on research and development. Today, we spend less than 1%. China and other countries are closing in fast. We have to develop and dominate the products and technologies of the future: advanced batteries, biotechnology, computer chips, and clean energy."[23]

In line with these remarks, President Biden's FY 2022 budget request to Congress, released at the end of May 2021, recommends historic increases across all civilian federal R&D granting agencies—an overall 9% percent increase to federal R&D, including a 10% increase to basic research and 14% increase to applied research (Figure 5). The proposal favors civilian

FIGURE 6 — COVID-19 EMERGENCY FUNDS TO R&D AGENCIES.



NOTE Five of the six emergency relief bills passed in response to the COVID-19 pandemic provide stimulus funding to R&D agencies, primarily to the Department of Health and Human Services. FY 2021 data does not include COVID-19 relief appropriations.
SOURCE American Association for the Advancement of Sciences Interactive Dashboards, 2021.

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defense, requesting a 21% increase to NIH and a 20% boost to NSF, while cutting basic research and applied research at DOD by 11% and 16%, respectively.[24] These totals align with the Biden administration's budget outline released in April 2021, as well as the president's infrastructure and jobs proposals announced earlier in spring 2021, which called for $250 billion for R&D activities and research infrastructure over the next four years.[25]

In parallel, congressional leaders in both chambers have introduced legislation addressing scientific and industrial competitiveness with China. In particular, two bills—Senate Majority Leader Chuck Schumer's (D-NY) Endless Frontier Act[26] and The NSF for the Future Act (H.R. 2225),[27] sponsored by Representative Eddie Bernice Johnson (D-TX-30), who chairs the House Science Committee—offer two distinct visions for augmenting NSF's research portfolio to meet current and future challenges to the U.S. research and innovation ecosystem. The Senate bill significantly increases NSF's budget and creates a new technology directorate that would work to translate basic research discoveries to broader commercial use. The House bill offers more modest funding and would also work to improve R&D's broader public impact, including the creation of a new directorate to address societal challenges.[28] A heavily amended version of the Endless Frontier Act was passed by the Senate on June 8, 2021, as part of a larger legislative package titled the U.S. Innovation and Competition Act (USICA, S.1260). This bill would appropriate $52 billion in emergency funding for domestic semiconductor manufacturing and R&D, authorize $29 billion to NSF's new technology directorate over five years, and increase the rest of NSF's annual budget from its current level of $8.5 billion to $12 billion over the same time period. The NSF for the Future Act, passed by the House on June 28, 2021, would authorize funding for its proposed directorate, starting at $1 billion annually and growing to $3.4 billion over five years, as well as roughly double the total NSF budget to $18.3 billion by FY 2026. Over the course of the next several months, the two chambers will work to reconcile these two bills into a final NSF reauthorization, in parallel with their annual appropriations negotiations before the October 1, 2021 deadline for FY 2022.

These ambitious proposals to vastly increase federal R&D spending face significant hurdles, including record federal deficit spending and an uncertain future for the discretionary budget, which could limit appropriations over the next several years even if a new authorization bill for NSF's budget or other key R&D agencies is passed. If Congress limits discretionary spending through new caps, federal funding for R&D across departments and agencies will likely suffer, unless it is prioritized over other discretionary programs. However, Democratic control of both the White House and Congress could provide short-term increases to funding for prioritized S&T research areas through the budget reconciliation process, where only a simple majority vote on fiscal legislation is needed and is not subject to filibuster.[29] This maneuver was used to pass President Biden's COVID-19 relief package in March and has been ruled by the Senate parliamentarian to be available for use once more during the coming budget cycle.

CONCLUSION

The Biden presidency arrives at a time when policy challenges reliant on S&T data and analysis have come into sharp public focus—from the COVID-19 pandemic, to record numbers of and intensity in U.S. wildfires and tropical storms in 2020, to mounting challenges relating to the tech sector's role in the U.S.' democracy, domestic economy, and foreign policy. While President Biden has made clear he will "listen to scientists," not all members of Congress and the public are willing to heed to scientists' voices on contentious policy issues, such as COVID-19 vaccine policy and climate change. Building public support for R&D, strengthening trust in scientific institutions and expertise, and increasing scientists' participation in decision-making related to S&T issues are critical to ensuring that scientific discoveries and innovation benefit the broader public and that increased investment in R&D serves the public interest. Scientists driven to action during the past four years of short-on-science budget proposals—by the Trump administration and public statements from President Trump and other federal officials that sometimes fell outside of scientific consensus—should continue their public outreach efforts to let state and federal policymakers know that advancing U.S. S&T is vital to the lives of all Americans and deserves special attention and support.

Academic scientists in particular need to effectively communicate the value of their research to the public and to policymakers to ensure their work addresses broader societal needs. This outreach can be accomplished through public lectures, meetings, and other events with civic groups, churches, K-12 schools, professional societies, and meetings with state and federal legislators. Universities and other research institutions should encourage and incentivize these avenues for public engagement through increased support of existing programs or funding new activities for interested faculty, postdocs, graduate students, and research staff. Scientists also need to listen to the concerns of the public and help address misconceptions. These "civic scientists" and their outreach are vital to helping promote science as a public good worthy of federal support.

By better communicating the progress and importance of their research, civic scientists can increase the transparency of the scientific process—from vaccine development to tech sector innovation to climate research and resilience—and serve as a force to promote ethical and equitable research and innovation policy as Congress deliberates on the future of research, innovation, and STEM education policy and funding during the first fiscal year of the Biden administration.

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