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System Re-engineering

A new policy framework
for the American R&D system
in a changed world

CSET Policy Brief

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Executive Summary

Policy for the U.S. research and development (R&D) system is still guided by ideas and institutions dating to the years after World War II. Yet the system has undergone fundamental change—both domestically and internationally—in the intervening 75 years. For America to maintain a leadership role in global R&D into the future, policymakers cannot simply repeat the solutions of the past. Instead, the United States needs a new, more systematic approach to R&D policy to leverage and optimize the diversity of the current system, to better manage the risks of an increasingly dispersed system, and to more effectively deliver the benefits of R&D to society. This policy brief offers a few examples of recommendations for a new and evolving role of the U.S. federal government in R&D.

- We provide a new framework for understanding the U.S. R&D ecosystem in terms of various actors and their inputs, and recommend full development of this framework to better leverage all domestic and partner R&D capabilities.
- The White House Office of Science and Technology Policy (OSTP) should lead the development of a new policy framework for the future of U.S. R&D, with a mandate to engage beyond the federal government, including state and local governments, industry, philanthropies, academia, and international partners.
- The federal government should support the creation of a real-time, open-source global R&D scanning capability to understand discoveries and developments in R&D around the world and make this capability and its outputs available across the R&D system.
- The federal government should undertake an inventory and gap analysis of the infrastructure needed for future R&D, including critical facilities and compute capabilities.
- The United States should work to preserve the benefits of open collaboration while prioritizing and maintaining national security, ensuring that different classes of institutions within the R&D system have fit-for-purpose protections.
- The federal government should encourage diverse approaches to R&D across the states and add support where broader benefits can be realized nationwide.
- Finally, the federal government should create specific collaborative programs with allies and like-minded countries in key areas of R&D, removing barriers and supporting the development of next-generation collaboration.

Vannevar Bush drafted *Science – The Endless Frontier* in 1945, creating a foundation for the U.S. R&D system—and ultimately, the global R&D system—for the next 75 years. He did not try to solve every problem laid before him in 1945. Instead, he assessed the past and present situations, identified areas of significant change requiring new approaches and offering opportunities, placed the challenges of his time within that context of change and identified a small number of interventions likely to have the most cross-cutting effect on the overall system. His roadmap was ambitious in its scope but didn't aspire to be global.

However, in today's context, a global approach is exactly what's needed. The United States again faces a moment of great change, but the current challenges and capabilities differ fundamentally from when the country was on the cusp of its postwar growth spurt. While still one of the largest world powers, this status is by no means assured. To extend the legacy of Vannevar Bush, we need to do far more than pay homage to it—we need to reinvent it.

Introduction

In 1960, American R&D accounted for 69 percent of the world total. The U.S. federal government funded the largest share of that global majority, with an ambitious postwar policy framework provided by Vannevar Bush in his 1945 report *Science – The Endless Frontier*. In 1946 and 1950, the Office of Naval Research and the National Science Foundation were established, followed by NASA and the Defense Advanced Research Projects Agency (DARPA) in 1958. Domestic government funding for R&D increased by a factor of more than 10 from the 1940s to the 1960s.

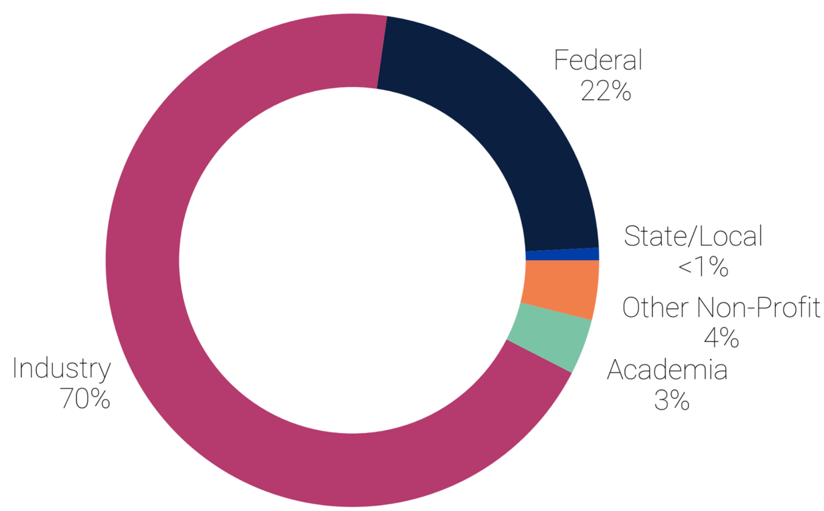
Fast forward 60 years to the present day. U.S. R&D accounts for just over a quarter of the world total. Chinese R&D has grown quickly to a size almost equivalent to the United States. A diverse group of countries—headed by Japan, Germany, South Korea, India, France, and the UK—makes up the other half. Led by the United States, and with other countries emulating its successful postwar model of innovation, the R&D system has globalized and grown to more than $2.2 trillion—a remarkable tripling of global investment in just the last two decades.

But this rapid expansion, both in scale and in the number of nations committed to R&D, brings new challenges. A great deal of attention is currently focused on China, and the Chinese Communist Party's efforts to advance technology to modernize its military and support authoritarianism at home and abroad. The U.S. policy response to date has been two-fold: first, a clampdown on collaboration with China, particularly focused on U.S. universities; and second, a call for the federal government to re-invest in R&D to boost American competitiveness. The release of the bipartisan *Endless Frontier Act* in late May 2020, with its call to "combat China" through $100 billion of new investment, links back to Vannevar Bush.

The security challenges and threats of this new globalized R&D system are real. But a response that only focuses on one part of the U.S. system (universities, for example), one other country (China), or one kind of input alone (federal government investment) won't be sufficient.

The U.S. R&D system of 2020 is fundamentally different from the system of 1960 or 1945. America no longer has unquestioned global leadership, and the federal government no longer funds the lion's share of U.S. R&D (Fig. 1). The challenge is often framed as a bilateral story of the United States and China trading places for the dominant role in global R&D. However, this narrative does not reflect reality: no one nation is likely to assume a globally dominant majority role in the foreseeable future. Leadership in this multipolar world will look very different.

Figure 1. Breakdown of domestic R&D by funding source (2018)



This figure shows the breakdown of U.S. R&D expenditures by source of funds in 2018. Source: National Science Foundation, National Patterns of R&D Resources: 2017–18 Data Update, NSF 20-307, Table 6, January 8, 2020, https://ncses.nsf.gov/pubs/nsf20307.

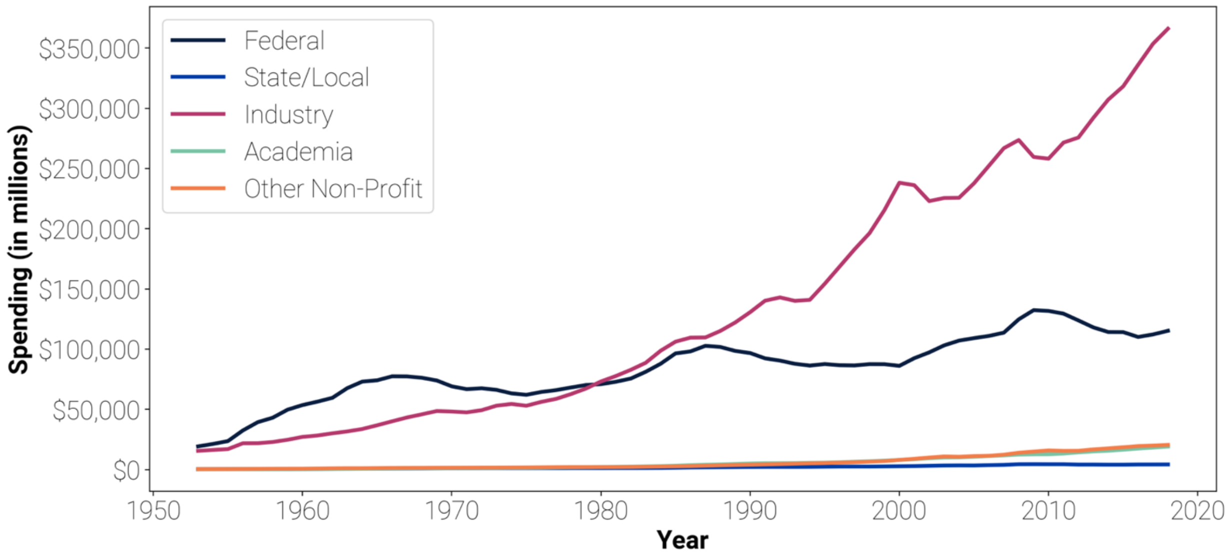
American innovation works best with flexibility, room for experimentation, and bottom-up creativity. Yet the federal government has a role to play in leading discussion about the U.S. R&D system as a whole, and analyzing how it can rise to the challenge of a changed world. As different actors in the system respond in their own ways to the altered global landscape, there needs to be a place for system-level thinking. New and different policy responses will be required to systematically develop and integrate innovation—from many more sources, both at home and abroad. The current moment calls for a new framework for American R&D, one that provides room for the creativity of individuals and institutions while ensuring short-term decisions do not undermine long-term competitiveness, and that supports and harnesses creativity for the benefit of society.

Thinking systematically about American R&D

With the presentation of his report to the President in 1945, Vannevar Bush called for government to take the lead in R&D at a time of declining industry investment and philanthropic support.

The situation today is very different. As of 2018, the federal government funded only 22 percent of U.S. R&D, with 70 percent of funding coming from industry (Fig. 2). Even in basic research, where the federal role is often thought most important, the U.S. government is no longer the largest funder. NSF survey data shows that in 2015, for the first time in the post–WWII era, federal agencies provided less than half—just 44 percent—of the $86 billion spent on basic research in America, as investments by industry, philanthropy, and academic endowments grew.

Figure 2. Domestic R&D by funding source (1953–2018)



This figure shows U.S. R&D expenditures by source of funds from 1953 to 2018. Source: National Science Foundation, National Patterns of R&D Resources: 2017–18 Data Update, NSF 20-307, Table 6, January 8, 2020, https://ncses.nsf.gov/pubs/nsf20307.

This shift has happened concurrently with a fundamental realignment of global R&D. Taken together, these two trends have led to calls for a reinvestment in federal R&D to boost U.S. competitiveness and maintain America's leadership role. We will first examine the domestic system within the United States, and then look at the ways it is connected internationally.

The domestic system has more critical actors than in 1960

Evolving over 75 years, the current U.S. innovation system is complex, diverse, and dynamic. Many actors beyond the federal government influence U.S. R&D, including but not limited to state and local governments, industry, philanthropy, academia, international partners, and the consumers of R&D—each with their own strategic goals and constraints. Leveraging the full capability of the American innovation system requires understanding and respecting all contributors to American R&D, not simply those most easily controlled by the federal government. A systematic understanding of the entire R&D system is needed, or future policy interventions run the risk of wasting scarce resources, or worse, reinforcing existing problems and inequalities.

Bringing creative minds to bear on the grand challenge of systematically re-engineering the R&D framework for the future is no small task. It is first critical to understand the full range of actors and inputs (see Figure 3 below). The columns list principal actors (there will be others) and the rows indicate some key inputs through which actors can shape and influence R&D. For example, as discussed in more detail below, the federal government uses all four inputs, but traditionally focuses on funding and shaping the policy and regulatory environment. Industry's predominant input has also been increasing funding for R&D, but it also generates a significant demand signal for education that leads to employment and, through internal training programs, human capital. Thinking through the inputs each actor can use and the range and scope of their influence will help government leaders understand the dynamics of today's innovation system. And end users can leverage this system of actors and inputs to create diverse paths for eliciting solutions from American R&D investments.

Figure 3: Matrix of U.S. R&D actors and inputs

		Actors					
		Federal Government	State & Local Government	Industry	Philanthropy	Academia	International Partners
Inputs	Funding						
	Human Capital						
	Infrastructure						
	Policy & Regulation						

This figure illustrates the wide range of inputs and actors in the U.S. R&D ecosystem. Even a simplified framework such as this allows us to see that the entire system must work in concert, rather than prioritizing one set of actors or inputs over all others.

New policies must leverage the full range of actors and inputs for national advantage rather than sub-optimizing across the board and stimulating counterproductive internal conflicts between actors or inputs. Policymakers should help individuals and institutions leverage the opportunity to work on a part of the system without needing to solve the entire problem set, within a systematic framework that allows one actor's inputs to be leveraged by others. Rules and policies should be fit-for-purpose rather than one-size-fits-all, offering as much flexibility as possible. Greater clarity is needed around what priority research should be open and available to others and what should be protected; this way, various actors will know explicitly what is expected of them and whether they feel they can support that expectation. And the framework itself must be flexible and adaptable, enabling anyone to add another column or row to accommodate themselves in the simplified framework.

Complex systems

The sheer number of institutions in the U.S. R&D system presents a challenge for new policymaking. A sprawling network of organizations and activities contribute to R&D through education, research, and collaboration. By re-engineering a framework for R&D policy that systematically analyzes and optimizes the points of greatest leverage, policymakers can turn this diversity into America's greatest asset.

In the section that follows, we provide a brief snapshot of this institutional diversity to highlight the fundamental differences between the R&D systems of 1960 and today. Harnessing this vast resource in new ways is not easy, but it is possible and, indeed, necessary for the U.S. system to remain competitive in this new world.

Under the federal government, national R&D agencies both fund and conduct their own research in extensive lab systems. For example, NASA, the National Institute of Standards and Technology, and the National Institutes of Health all house significant laboratory enterprises. The Department of Energy's system spans the country with its own ecosystem of funding agencies and 14 National Laboratories while the Department of Defense's R&D enterprise encompasses more than 60 laboratories of its own.

State governments also have their own initiatives, largely under the label of innovation programs focusing on the development and translation of university R&D, investments in infrastructure, and support to entrepreneurs and start-ups. Examples vary widely: Massachusetts, for instance, created a broad-reaching set of programs, including matching grants for research infrastructure, a network of accelerators and incubators to grow the entrepreneurial ecosystem, and investment in specific sectors like next-generation manufacturing via the Massachusetts Manufacturing Innovation Initiative, as well as rural broadband to boost inclusivity.

Utah, with a vastly different culture and geography, also established an impressive set of initiatives to support the development and retention of talent, growth of start-ups, and the production of marketable products through investments in infrastructure and entrepreneurs. This was achieved through efforts like the Utah Science Technology and Research initiative. The Milken Institute publishes an index of State Technology and Science that provides perspective on the large variation among states, and SSTI—a national nonprofit dedicated to engaging across all 50 states on science, technology, innovation and entrepreneurship—has tracked data on R&D intensity at the state level since 2002.

With over half a trillion dollars in endowments, academic institutions also sustain and grow R&D. The National Center for Education Statistics counts more than 4,300 degree-granting institutions that make up the U.S. system of colleges and universities. U.S. News ranks 1,400 universities spread across the country that are regionally accredited and offer four-year undergraduate degree programs. Of these, approximately 200 are leading, research-intensive universities. And endowments at academic institutions, especially a top few, are growing; in the 2016–17 fiscal year alone, the market value of endowment funds of colleges and universities increased 10 percent, from $544 billion to $598 billion. This investment allows academic institutions to sustain and build needed infrastructure and research critical to attracting not only additional funding but also the best talent.

Philanthropic support for R&D is also on the rise, and while the total funding may be small relative to the amount from industry and government, the impact is often large. With less external accountability and the potential for patient funding, we see a range of interesting choices that would be more difficult in government or industry: high-risk support for big ideas (for example, the Breakthrough Prize Foundation); implementation of vetted approaches to solve real challenges (the MacArthur Foundation's 100&Change and Lever for Change); and experimentation with different structural models for R&D (the Howard Hughes Medical Institute). These are only a few examples; understanding the value and independence of this source of support for R&D is crucial yet, it is currently undervalued and underleveraged by government.

Since outpacing the federal government in R&D investment in 1980, industry has accounted for the largest portion of U.S. R&D spending. This trend continues to restructure the R&D system as industry forges direct relationships with universities for basic research and talent pipelines, with start-ups through company venture capital organizations, with state and local governments through education partnerships and innovation centers, and with markets that are now global.

The R&D spending of the major West Coast technology companies (Amazon, Google, Intel, Microsoft, Apple) now far outstrips the spending of the major defense contractors traditionally connected with the federal government (Boeing, Lockheed Martin, Raytheon, Northrop Grumman). The tech companies have created their own ecosystems of research collaborations, funding, and hiring pipelines with universities, as well as innovation centers offshore. Their ability to influence the economic geography of the United States was evidenced by the recent competition between cities for the new Amazon HQ2. Moreover, the technology industry actively lobbies for specific policies and regulations (or lack thereof) affecting business, infrastructure, and education.

The defense sector provides a perfect example of the change in the domestic R&D system. Historically, it played a significant role as a primary customer for cutting-edge technologies. Defense R&D still represents the largest portion of federal government spending, but the proportion has declined. With increasingly complex procurements and declining purchase quantities, defense now has a smaller impact on industrial R&D as well. The relationship between defense, the federal government more broadly, and the major R&D-performing companies has fundamentally changed. Rather than being the major procurer and purchaser, government may now need to broker collaboration between companies in open architectures that benefit the system as a whole. Government is also seeking new ways to work with tech companies to protect national security, while also reckoning with the increasingly global nature of their bottom lines.

Just as there is great diversity in actors across the U.S. R&D system, so too is there a range of important inputs. Dollars often offer the easiest proxy for measuring the size and health of the R&D system, but success is about much more than money. It is beyond the scope of this paper to attempt to provide a detailed analysis of the full range of inputs, but the matrix in Figure 3 highlights a few of particular importance that offer opportunities for policy and programmatic interventions. Much has already been written about the importance of talent and human capital for R&D and competitiveness; we discuss this particular input below as an example of the importance of thinking domestically and internationally for future R&D policy. But infrastructure and regulatory settings are equally deserving of analysis, both at home and abroad.

A new world order

Human capital in the R&D system highlights the dependencies across different actors and inputs within the system at home and abroad. The development of the talent necessary for future innovation involves the federal government, but the states and academia play crucial roles. And as the largest funder of R&D, industry is now also the primary market signal for employment, affecting the education choices the future workforce will make. Coherent policy for future competitiveness requires more than simply prioritizing "hot topics" of emerging R&D and investing federal funds: without a talented workforce ready to take up the challenge (or with various actors across the system poaching talent from one another) the system as a whole will weaken.

The United States cannot maintain its leadership role if it can't think systematically about its contribution to, and dependence on, a diverse and dynamic global system. The open model of international education and research created by the United States over the last 75 years attracts talent from around the world to study and work in America. This enables the United States to leverage a global talent resource rather than being constrained to talent available in just the United States. This is an asset to be protected. Top R&D talent from overseas, now more mobile than ever, makes up roughly 60 percent of PhD-qualified computer scientists and engineers in the U.S. workforce, with the largest groups coming from India and China. But other countries now compete for this talent.

As global R&D investment has tripled over the last 20 years, many countries have pursued policies that borrow from—and seek to emulate—the successful U.S. model. This approach has delivered many benefits to the United States, with more foreign-born talent and collaborative links to the R&D of other nations than any other country. But leveraging those advantages necessitates different policies than those of the past. U.S. R&D policy requires a new framework for mitigating the risks and threats, while still capturing the advances, of a globalized system.

The current, singular focus on the rise of China and its R&D priorities has created a split between the U.S. national security community—who raise legitimate concerns about technology, security, and human rights—and economists—who point to the importance of international flows of people, technology, and capital in historic and current national success. Both perspectives are important: openness and security need not be seen as mutually exclusive. A more useful approach to this challenge would be to analyze the system as a whole, clarify what outcomes are desired, and then determine how the U.S. R&D system should respond, leveraging its unique assets. In this environment, a diverse institutional landscape can be a major advantage, provided that people, ideas, and capital can move within the system as circumstances change.

U.S. universities are now highly internationalized, collaborating broadly in research and drawing in the world's best talent, along with significant tuition dollars supporting wide-ranging domestic efforts. These institutions provide a system unlike any other for America to stay connected to new cutting-edge knowledge and technologies worldwide, providing industry and government with significant opportunities for leverage. Universities and basic research should remain as open and linked to the global system as possible, while also connecting with institutions in the national system for more applied or sensitive R&D. Rather than creating a competitive or territorial domestic system, policy attention should focus on making it easier to move people and projects between universities and other parts of the system as needed, ensuring there are talented people and places where both open science and secure development can occur.

In a moment when the vast government laboratory system could be most useful—providing a secure bridge between the openness of the academic environment and the necessary security for our national needs—attention has focused elsewhere and trust in government institutions has declined. By instead asking universities to do more applied work, to patent and spin off companies, both security and openness become more difficult. Policy should focus on letting each part of the R&D system play to its strengths.

Domestic R&D should be understood as an ecosystem, in which the effectiveness of each component is maximized. The same logic should apply to U.S. connections with international partners. In the face of a shifting global system, the United States should invest in new ways to work closely with allies and like-minded countries. Focusing only on China misses half of global R&D, which now occurs outside of the two largest powers.

This does not imply that the United States should shun all connections with China in R&D. America is at its most competitive when it taps the broadest pool of global talent and ideas, and it will be increasingly important to maintain links even to countries with whom strategic relationships are difficult. Forcing a total decoupling or bifurcation of the global innovation system will likely prove counterproductive and deprive the United States of a large portion of global knowledge, talent, and technology development that will be leveraged by others. It is also unclear that all U.S. allies would accept this global bifurcation as a good strategic choice and simply cut off R&D ties with China.

However, it is also long past time to craft focused innovation partnerships with close allies allowing faster, less burdensome environments for the rapid co-creation of science, technology, and global standards and norms. America cannot adopt a one-size-fits-all approach to deepening cooperation with its allies in key R&D areas. Different countries have their own strengths, international connections, innovation cultures, and internal constraints. A systematic U.S. approach will tap those capabilities, acknowledge the constraints, and bring like-minded partners into focused partnerships where they can help drive faster outcomes, all while protecting national security and advancing shared values. The United States must know specifically what it hopes to achieve, use open source analysis to understand the overlapping, complementary, or competitive nature of various partnerships with other nations, understand the strategies of those nations, and aggressively remove barriers to collaboration supporting U.S. goals, such as unhelpful export control rules and other hindrances.

Rather than a binary race for dominance between two countries, this conception of American R&D reflects a shift to a more dispersed landscape, with expertise, funding, and infrastructure scattered across the globe. A coherent policy framework for engaging with this new world will require systematic analysis and clarity about the different roles, relationships, and dependencies of the various actors in the R&D system. This is a different kind of leadership.

Recommendations

Only a systematic approach will enable effective policy for American R&D in this new world. No one person or organization holds all the answers—much less the money, talent, infrastructure, or power—but the federal government has a crucial role to play in empowering actors in the system to work together, and in connecting domestic efforts to the international system. Going forward, the federal government's place in R&D policy is not one of central control; rather, it must augment its current funding role with an equally important role as the connective tissue between the many critical actors in the ecosystem.

We conclude below with a few suggestions for next steps. However, perhaps the most critical next step is to start a broader conversation about how to expand and elucidate a new R&D framework, fully understanding the dependencies in the system and leveraging all American and partner capabilities.

The matrix and recommendations below offer a starting point, but end users of all kinds should imagine the R&D ecosystem in terms of their own needs, roles, and opportunities to get results from it. Individuals and organizations who don't see themselves in the matrix can simply add their own columns. We do not purport to have all of the answers—in fact, that is exactly the point. Traditional top-down interventions ignoring the full complexity of the system cannot address the dynamic domestic R&D environment and the multipolar future. This moment calls for all actors to step up and embrace their own power to impact the bigger mission space.

When we start to think about the role of the federal government within this framework, the following needs emerge. This is by no means an exhaustive list of options and priorities, and we welcome feedback on other ideas and needs.

- The White House Office of Science and Technology Policy (OSTP) should lead the development of a new **policy framework for the future of U.S. R&D**, which will allow for the prioritization and evaluation of the right policy interventions across the system. OSTP should be given a clear mandate to engage beyond the federal government, creating more structured links with state and local governments, industry, philanthropies, academia, and international partners. To inspire others to apply the framework in local contexts, ensure R&D is brought to bear on problems at every level.
- The federal government should support the creation of a real-time, **open-source global R&D scanning capability** to understand what is happening in R&D around the world and to better align partnerships and understand competition. This capability should make actionable open-source data analysis available across the system—not simply to government agencies. This should leverage new technologies and may require a public-private partnership. This effort should include information not only on international developments in R&D, but also on best practices across the U.S. system to stimulate collaboration and increase the translation of basic research to economic productivity and national capability.

- The federal government should undertake an inventory and gap analysis of the **infrastructure** needed for future R&D, including critical facilities and compute capabilities. This should be informed by international infrastructure investments and the opportunity to share with partners. The cost of development and sustainment of major infrastructure is not trivial; new (or sometimes old) models that leverage state matching funds or industrial, academic, or philanthropic use agreements could make this more economically feasible, as well as ensuring entrepreneurs and researchers have access to a wide range of world-class R&D infrastructure.
- The new framework for U.S. R&D should preserve the benefits of open collaboration while prioritizing and maintaining national security. Rather than applying one-size-fits-all rules across the entire system, government should ensure that different classes of institutions within the system have fit-for-purpose protections. Government should prioritize investments that **incentivize movement within the U.S. system**—for example, for university researchers to move a project into the National Labs when necessary and for the National Labs and defense labs to easily transition projects and technologies to industry without fighting over intellectual property.
- The federal government should **encourage diverse approaches to R&D across the states** and add support where broader benefits can be realized nationwide. For example, the federal government could create a new program to match state funding to land-grant universities taking a lead on critical challenges as defined at the state and regional level, and then disseminate best practice through the rest of the system. These funds could be matched not only by states, but also by industry, local or regional philanthropies, or academic endowments.
- Finally, the federal government should **create specific collaborative programs with allies and like-minded countries in key areas of R&D**—removing barriers and supporting the development of next-generation collaboration. Existing programs that support global exchange to build mutual understanding should be maintained but are not sufficient for this new world. New focused programs with like-minded partners are needed to leverage investments and speed up R&D in key areas of mutual interest, while ensuring rapid capability development and strengthening of democratic values.

Conclusion

Debates about U.S. R&D policy often employ the metaphor of "seed corn" to describe necessary investments in basic research—traditionally made by the federal government—that then lead to future innovation and competitiveness. As U.S. federal government funding for R&D declines as a share of total R&D both nationally and globally, advocates have called for a renewed focus on investment in this seed corn, modelled on the post–WWII boom of the *Endless Frontier*.

Investments in basic research are a critical part of a systematic approach to R&D. However, we assert that while necessary, such investment is not sufficient. A farmer needs to ensure enough seed corn to weather a bad year and survive into the future, but many other investments must be made simultaneously for those seeds to reach abundance. Soil, water, weather, harvesting, transport, global markets, and a long-term, sustainable and equitable approach to farming itself are all vital parts of realizing the potential of that seed.

Similarly, U.S. R&D policy at the federal level must now progress from its successful postwar framework to a new framework for the 21st century. The original *Endless Frontier* did not just increase federal funding—it created new institutions across the country, re-cast the role of government, and offered a global model for others to emulate and collaborate with. It is time once again for creative systems engineering on U.S. R&D. Though American leadership will look very different now than it did 75 years ago, it remains as important as ever.

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