National Science Foundation

Connected Horizons
New opportunities in a changed landscape

by Darío Gil, Ph.D
National Science Board Chairman
September 2024

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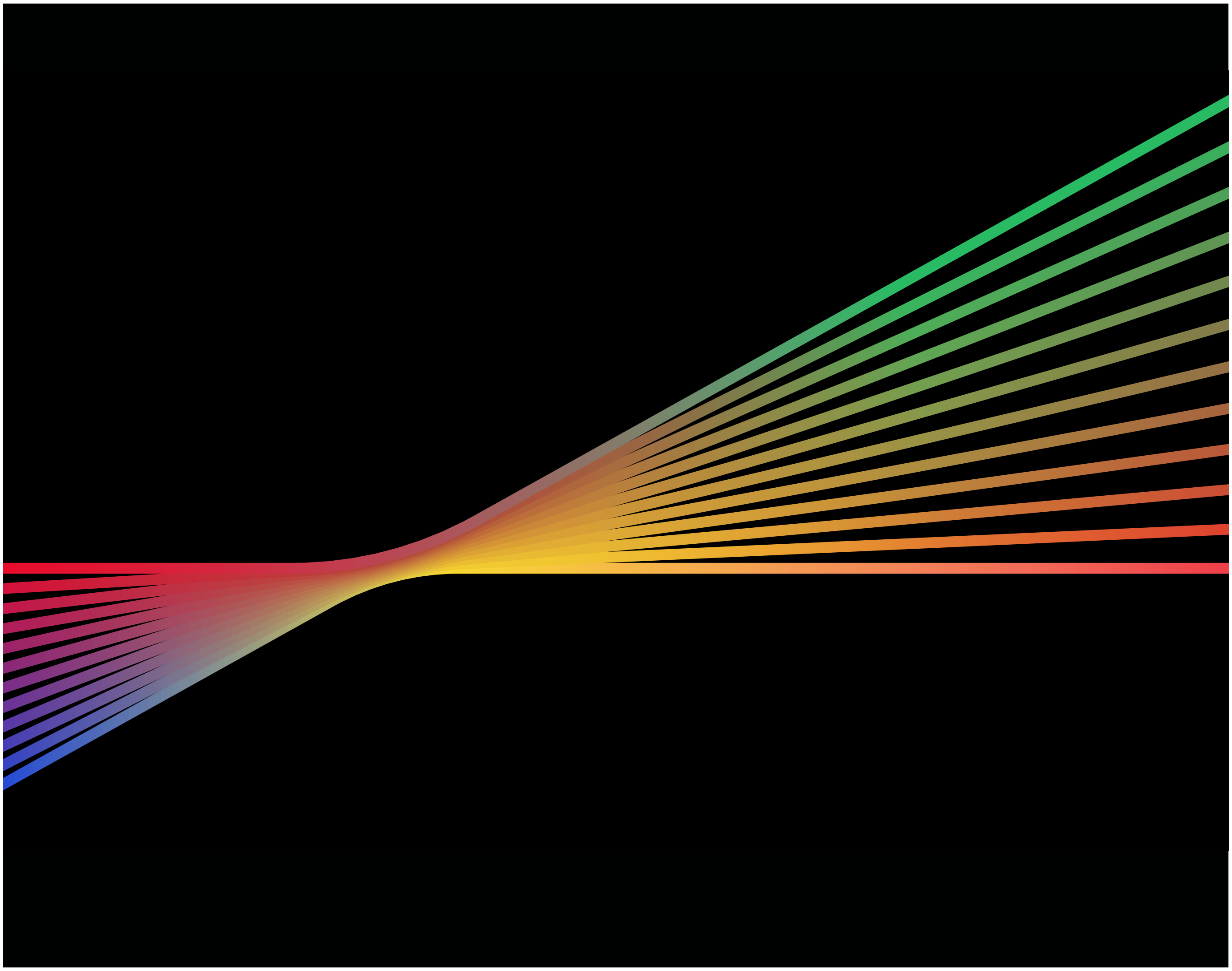


The first quarter of the 21st century has been an incredibly transformative time, and next year will mark the 75th anniversary of the National Science Foundation. It's important to reflect on the events that have helped to shape the current science and technology (S&T) landscape and highlight the opportunities we can embrace, and the changes we must make, to secure the United States' S&T leadership for the next 75 years and beyond. And as we adapt our S&T ecosystem for this new landscape, we must continue to deliver the benefits of scientific and technological progress to all Americans.

In 2020, the National Science Board published *Vision 2030*, a 10-year science and technology roadmap for the U.S. We are already halfway through the decade and can agree that the world has changed in these past five years far more than we could have imagined. All of which makes this a perfect moment to take stock: Where have we been, where we are now – and where do we want to go?

The Endless Frontier Era

Let's begin by going back to 1945. World War II marked the waning of European S&T dominance and, in part due to the U.S.'s welcoming of refugee scientists, the start of U.S. S&T leadership.

In the last months of the war in 1945, initial steps were being taken to create a new set of S&T institutions. My own institution, IBM Research, was itself born in March of that year.

In July 1945, Vannevar Bush, the head of the wartime U.S. Office of Scientific Research and Development, delivered his famous report to President Truman: *Science - The Endless Frontier*. In this visionary treatise, he proposed the creation of a "National Research Foundation" to leverage the successful collaboration among government, university, and industry in science and technology in support of the war effort and extend it for a new era of peace. He emphasized the scope and durability of his vision: "Scientific progress is one essential key to our security as a nation, to our better health, to more jobs, to a higher standard of living, and to our cultural progress."

Thus began a wave of development of S&T institutions. This period, the "Endless Frontier era," emerged from the belief that science is more than just a "hinterland" for exploration. It is a fundamental tool for ensuring the nation's security, welfare, health, and prosperity.

President Truman officially signed the National Science Foundation Act in 1950. The NSF was a new institutional model. While earlier federal government S&T investments and institutions had focused on specific topics in specific areas, the NSF would support fundamental research across all non-medical fields.

The Development of S&T Institutions

The truth is, we have developed mythologies about science and innovation – about how it works, about who does science, and about who supports which components of the work.

The mental model of science is that it starts with government funding of basic research at colleges and universities and transitions into industry for the final stages of development – even though there have always been feedback loops, and funding loops, between and across sectors.

We tell a story about Bush's *Science, the Endless Frontier* as well, suggesting that it was embraced more readily, consistently, and fully than it actually was. Congress spent five years debating Bush's vision of a National Research Foundation with total independence and a broad scope. Meanwhile, the world was moving – and fast. The National Institutes of Health added its extramural grant program. And the U.S. Navy created the Office of Naval Research and developed partnerships with universities. By the time the NSF was established, its remit and independence were very different – and greatly diminished – relative to Bush's vision.

The real federal science and technology story over the past 75 years is not a tale of broad exploration of fundamental science across all fields, spearheaded by an independent foundation of the type Bush envisioned. Rather, it is a largely mission-driven story, with shock events driving institution-building and research and development budgets. Below is just a partial list.

- The launch of Sputnik in 1957 led to a rise in defense R&D, the establishment of NASA and DARPA, and the passage of the National Defense Education Act to develop talent, particularly in STEM.

- The energy crisis in the 1970s led to the creation of the Department of Energy.

- The end of the Cold War and sequencing of the genome paved the way for doubling the NIH's budget in the 1990s, and with 9/11 and the anthrax scare, that doubling came to fruition.

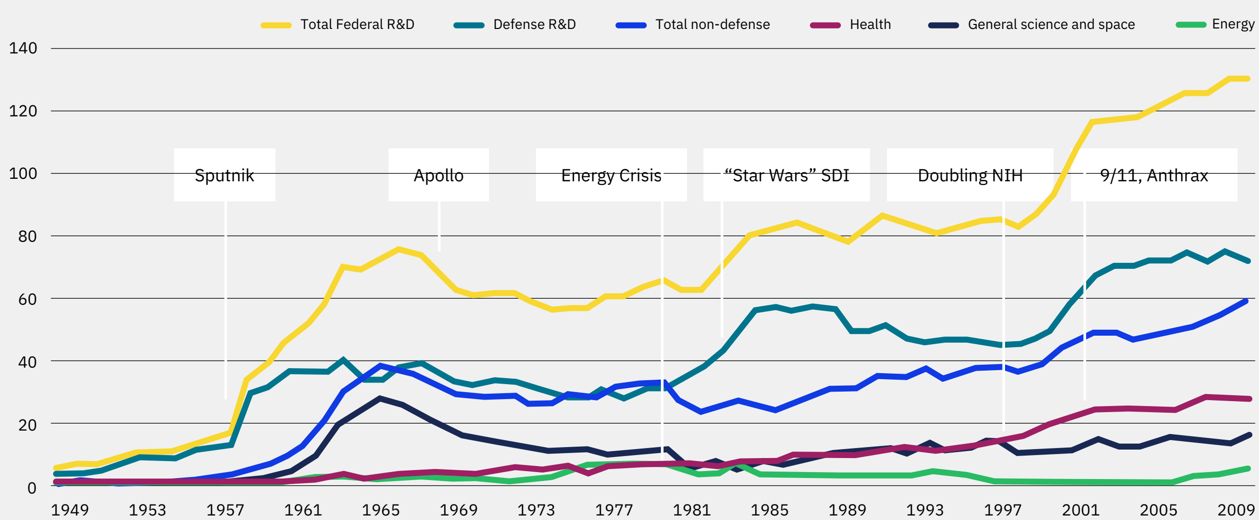
- More recently, the U.S.'s reliance on global supply chains, particularly for silicon chips, highlighted some vulnerabilities, leading to the CHIPS & Science Act of 2022.

The real federal S&T story is a largely mission-driven story, with shock events driving institution-building and research and development budgets.

Institutions did not emerge and grow exactly as Bush imagined they would, but his arguments, and the wartime successes under the Office of Scientific Research and Development, ultimately led to a transformational change in the nation's S&T ecosystem: The federal government took on a new role as a funder of basic research across all fields, and government and academia began establishing partnerships. (see figure 1, Shock events spur institution building)

Figure 1

Shock events spur institution building
Billions of constant 2005 dollars



Source: United States: Office of Management and Budget (OMB), "OMB Historical Table 9.8" (2024)

Ebbs and Flows in R&D Funding

As the U.S. S&T ecosystem evolved through the Endless Frontier era , private sector research and development began playing a key role. In the early 20th century, AT&T, DuPont, GE, and Kodak created corporate research laboratories. Other companies, including IBM, followed suit during the interwar years, and business R&D began to really grow.

During the 1950s, federal funding augmented the investments that businesses were making in R&D, and, in fact, federal funds were the largest source of support for R&D conducted by private business. The federal government spent large sums well into the 1960s to support use-inspired basic research and development work in the private sector. These labs were very successful in addressing technical challenges and yielding new products. They also made profound contributions to the natural sciences and computer science. **(see figure 2, U.S. R&D expenditures: Business, federal government)**

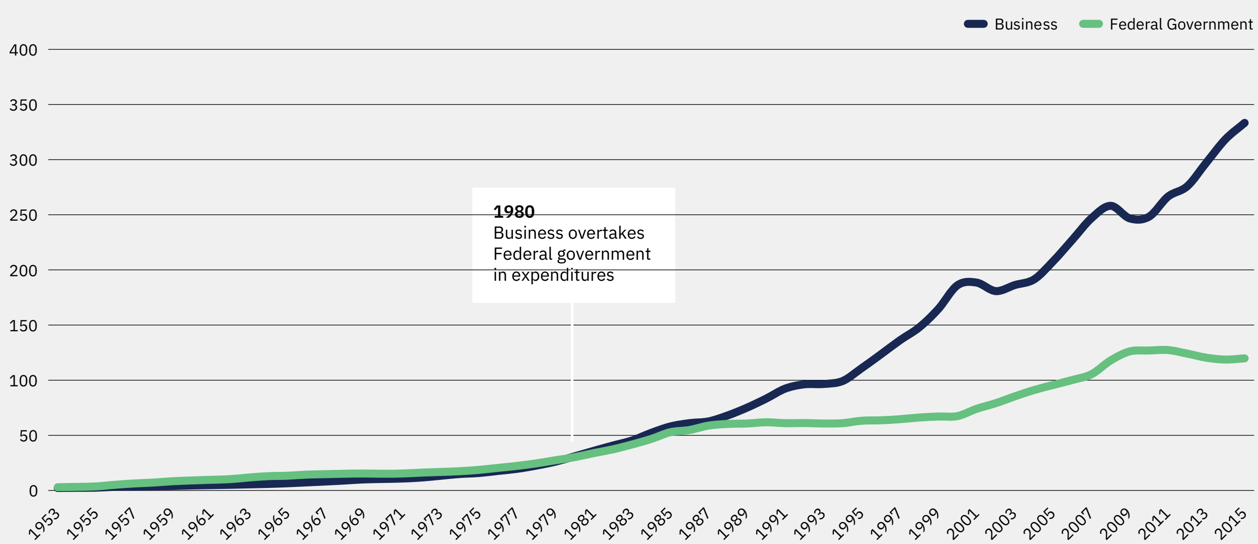
But after 1968, the federal government began to pull back its funding for business R&D, and the share of total R&D that was federally funded started to decline.

During the 1950s, federal funding augmented the investments that businesses were making in R&D, and, in fact, federal funds were the largest source of support for R&D conducted by private business.

Business R&D remained strong. Then, in 1980, came a significant milestone in the evolution of post-war S&T: Business investment overtook the federal government as the

Figure 2

U.S. R&D expenditures: Business, federal government
Billions of current U.S. dollars, 1953-2015



Source: National Science Board, NSF. *Science and Engineering Indicators* 2024

largest funder of R&D, returning to the pre-WWII pattern.

Academia's role in scientific research dates to the latter half of the 19th century with the establishment in the U.S. of the modern research university. While the federal government has been the primary source of funding for academic research since the Endless Frontier era, in more recent years, funding of research by higher education itself has been on the rise. **(see figure 3, U.S. R&D expenditures: higher education, other)**

Private philanthropy also has a deep history in research and education. In the late 19th century, philanthropy was a significant contributor to the establishment and endowments of many of the U.S.'s leading research universities, and prior to WWII, philanthropic entities like the Rockefeller Foundation played a significant role in U.S. science funding.

Today, philanthropy still represents a fairly small fraction of research funding overall, but Robert Conn, former president and COO of the Kavli Foundation, recently argued that the U.S. may be entering a second significant era of direct philanthropic funding of research. It's a possibility worth keeping an eye on.

Arriving at a Changed Landscape

Today's landscape has evolved markedly from that of Vannevar Bush's time. Three key features are foundational to this changed landscape:

- **Business funding has risen dramatically, with an accelerating growth rate.**

- **U.S. leadership in science and engineering is eroding, in part due to China's rising investment in science and technology.**

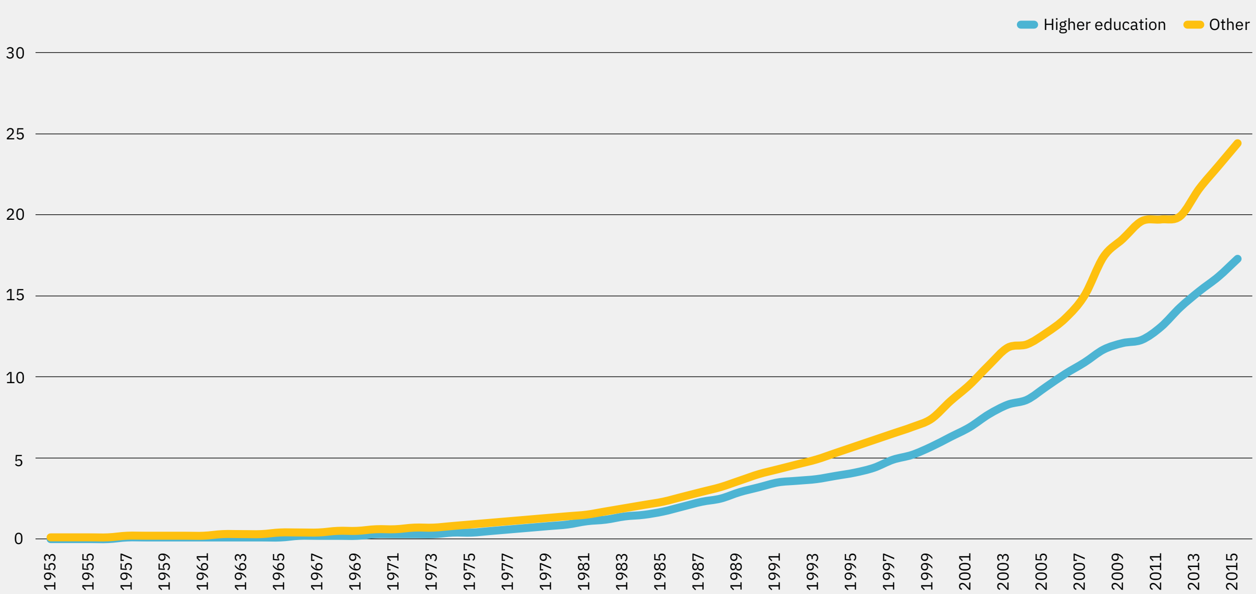
- **The number of jobs requiring STEM skills is rapidly increasing.**

At the same time, public trust in institutions continues to erode. This is a global phenomenon. Science and scientists still enjoy high levels of trust relative to many other institutions, but science is not immune from this trend.

In what ways has the shift in U.S. funding for S&T impacted the landscape? Since 1980, business has been the biggest funder of U.S. R&D, and over the past decade this trend has dramatically accelerated. This is a clear change since the

Figure 3

U.S. R&D expenditures: higher education, other
Billions of current U.S. dollars, 1953-2015



Source: National Science Board, NSF. *Science and Engineering Indicators* 2024

mid-20th century: Business has shifted from being primarily a beneficiary of investment to serving as a driver of it. **(see figure 4, U.S. R&D expenditures: all sectors)**

It's important to note that private sector R&D is very concentrated, clustering in a few specific sectors such as information technology and pharmaceuticals. Software R&D alone has grown dramatically, representing about a fifth of business funding in 2006 to over 40% in 2021.

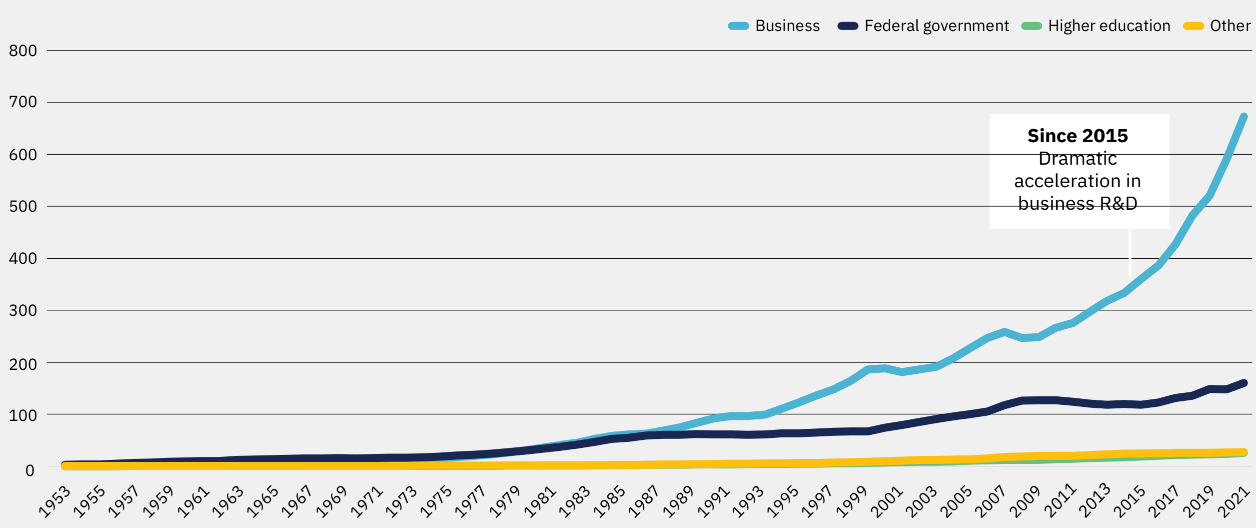
Though the lion's share of industry R&D funding goes to experimental development, the private sector also conducts fundamental research. In fact, business funding of basic research has accelerated over the past decade. Whereas the federal government funded a significantly higher percentage of basic research than the business sector as recently as 2018, the latest data shows that industry has nearly closed that gap. In 2022, the federal government and business funded 39.6% and 37.1%, respectively, of all basic research in the U.S. **(see figure 5, Funding basic research)**

My own institution is a prime example. In mathematics, IBM contributed algorithms and models that are used nearly everywhere, from matrix multiplication algorithms to universal hashing, Mandelbrot fractals, and the modern

Business funding of basic research has accelerated over the past decade.

Figure 4

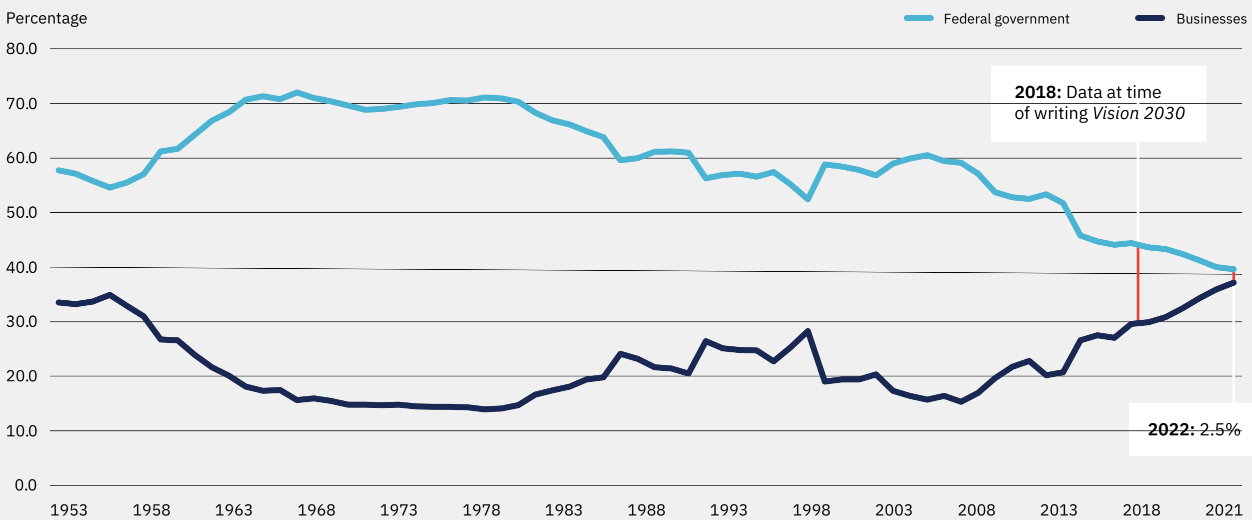
U.S. R&D expenditures: all sectors
Billions of current U.S. dollars, 1953-2022



Source: National Science Board, NSF. *Science and Engineering Indicators* 2024

Figure 5

Funding basic research (1953-2022)

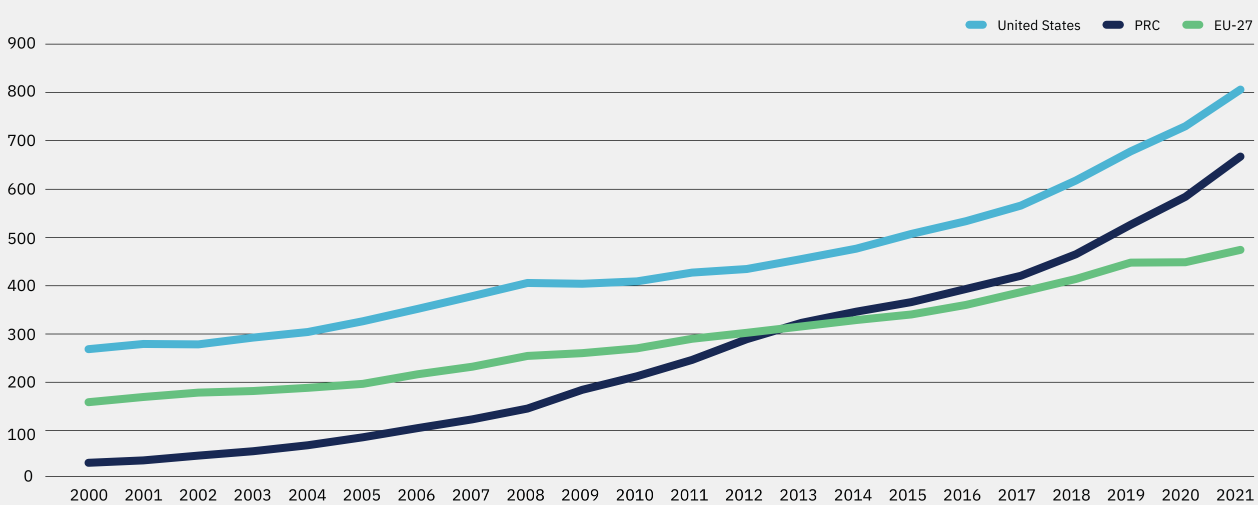


Source: NCSES InfoBrief, Analysis of Federal Funding for Research and Development in 2022: Basic Research, NSF 24-332. 15 Aug 2024

Figure 6

Gross domestic expenditures on R&D: USA, PRC, EU-27

Billions of current PPP U.S. dollars, 2000-2021



Source: National Science Board, NSF. *Science and Engineering Indicators* 2024

generic version of the fast Fourier transform. And more recently, in quantum information sciences, IBM invented quantum teleportation, put the first quantum computer in the cloud for anyone to use, and brought the first fully integrated quantum computer to the world, to be deployed outside the confines of our labs.

We should celebrate the contribution of business research and development, which drove U.S. R&D to 3.5% of GDP in 2021. But we should also be clear that it is not a substitute for federal R&D. The two are complementary.

The business sector has long relied on the federal government to make the crucial initial bets on new ideas across all scientific fields. Many of the S&T advances that underpin today's commercial technologies and industries are rooted in research conducted decades before practical applications were realized. Simply put, federal investment in fundamental research today enables the emerging industries of tomorrow.

One consequence of the success of U.S. S&T over the past 75 years is that S&T now has the same kind of economic and geopolitical importance as trade or military alliances. It is a major playing field for economic and defense competition.

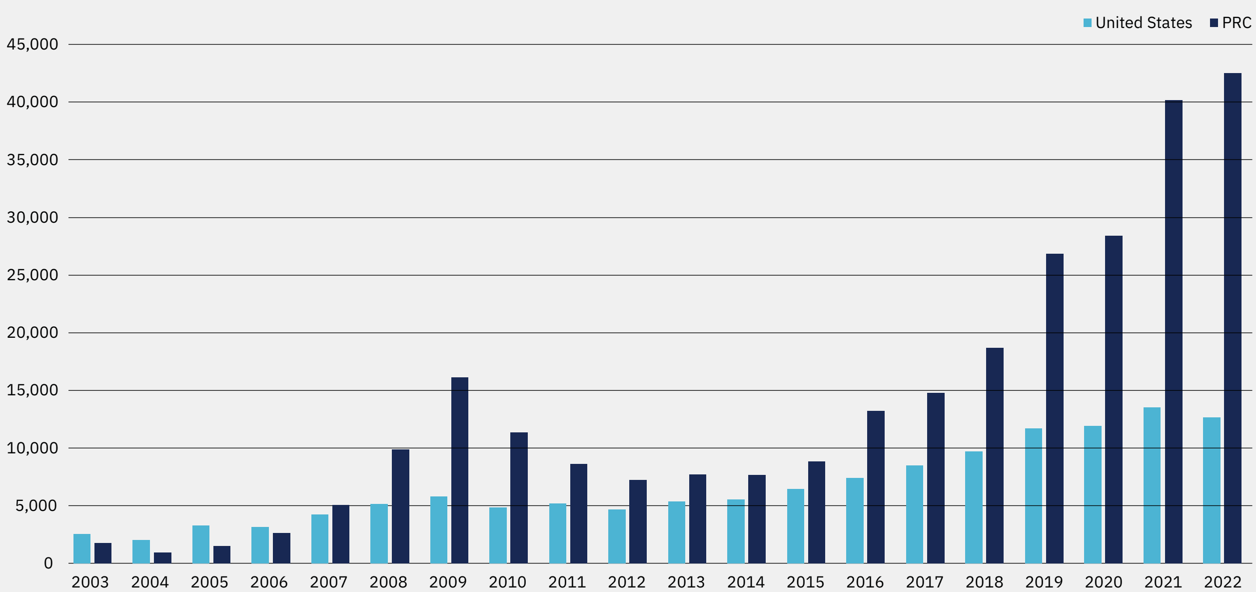
This leads to the second feature of the changed landscape:

China has surpassed the U.S. in research publications, patents, and knowledge- and technology-intensive manufacturing.

China is our biggest competitor, but it is also one of our biggest collaborators. China's rising prominence in S&T began with sustained increased funding of R&D at levels that eclipsed those of the EU around a decade ago. Those investments are now bearing fruit. **(see figure 6, U.S. R&D Expenditures: USA, PRC, EU-27)**

Figure 7

AI related S&E articles: USA, PRC
2003-2023



Source: National Science Board, NSF. *Science and Engineering Indicators* 2024

For the past decade, with each release of the NSB's *Science & Engineering Indicators* report, the National Science Board has sounded the alarm as the U.S.'s lead has eroded on more and more global S&E metrics. China has surpassed the U.S. in research publications, patents, and knowledge- and technology-intensive manufacturing. And now, for the first time, China is awarding more PhDs in S&E than the U.S.

China is a formidable competitor in areas of technology critical for national security, including AI, semiconductors, quantum computing, and biotechnology. China now holds more S&E patents than the U.S. Looking at AI specifically, China holds more patents and its publication rate is far outpacing the U.S. **(see figure 7, AI related S&E articles: USA, PRC)** Of course, this is not a zero-sum story. China is also our largest collaborator in published research, including in AI. **(see figure 8, AI related S&E articles)**

The third feature of the new landscape is centered around education and the workforce. At a moment when S&T is increasingly important to the nation and there is increasing competition from China, the U.S. is facing a STEM talent crisis.

Trained and talented people drive innovation by carrying promising ideas from the laboratory to the workplace. It's

Figure 8 **AI related S&E articles**

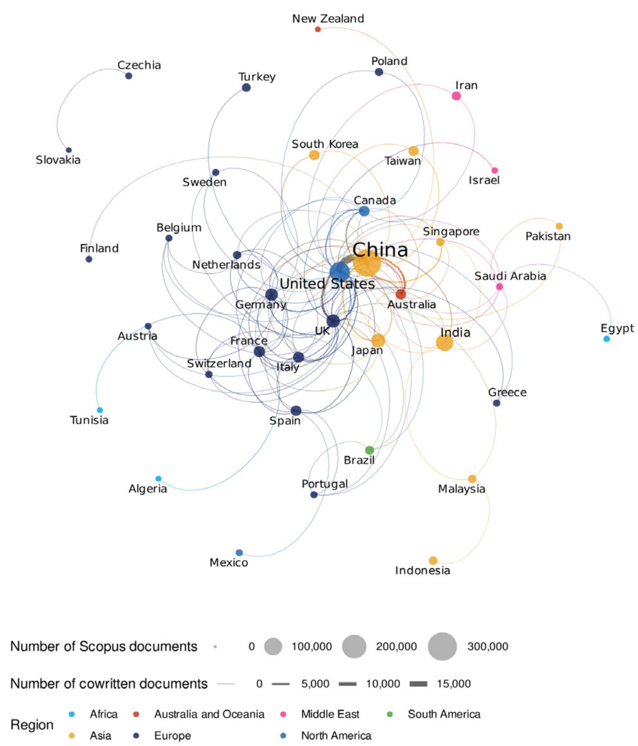
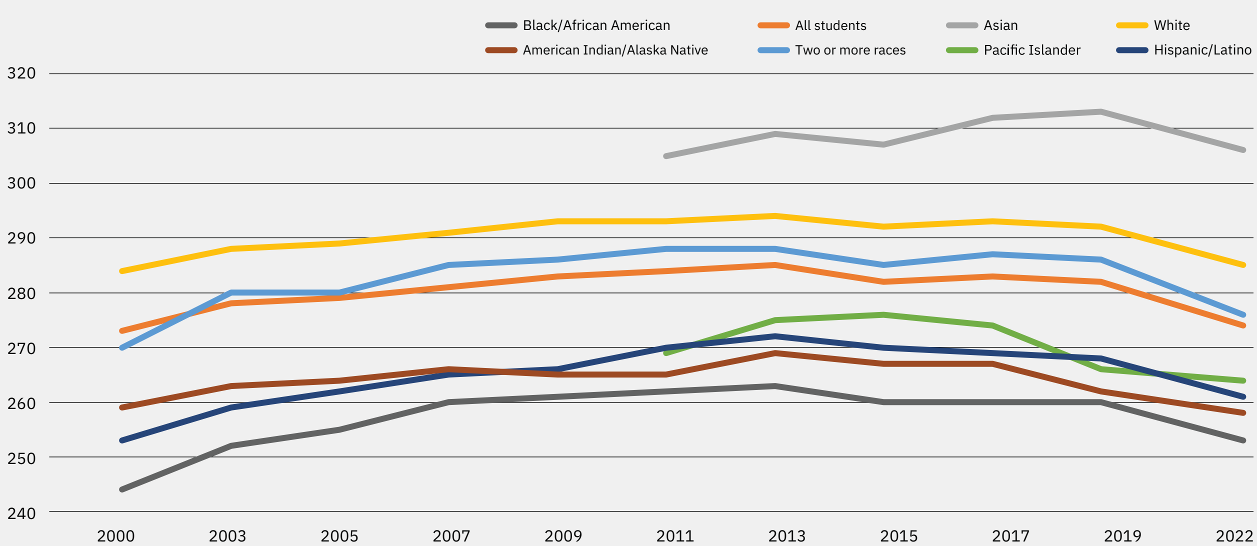


Figure 9

Gains in K-12 STEM performance have been erased

Average math test scores from 2000 to 2022



Source: National Science Board, NSF. *Science and Engineering Indicators* 2024

deeply worrying that the U.S. is failing to adequately educate and nurture its domestic students and workers.

Among advanced economies, U.S. K-12 students have long been merely “middle of the pack” in STEM performance. Data from 2022 shows that the little gains that U.S. students made in mathematics proficiency in the past 20 years were erased during the pandemic. **(see figure 9, Gains in K-12 STEM performance have been erased)** These declines are the largest among individuals from race and ethnicity groups that are already marginalized in STEM – the “Missing Millions” – and for individuals from low socioeconomic status households.

Fortunately, the U.S. continues to be a beacon for talent from around the globe. The share of U.S. S&E doctorate-level workers who are foreign-born has grown from 27% in 1993 to 43% in 2021. **(see figure 10, International talent is essential)**

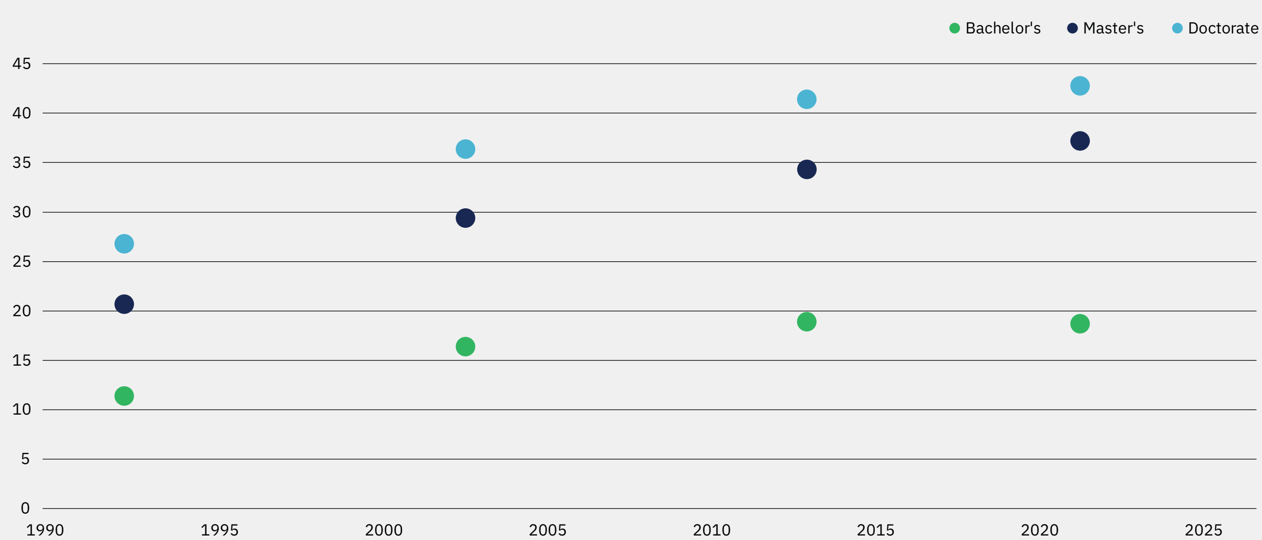
The fact that the U.S. attracts talent from around the globe is a key strength and source of vitality for the nation’s S&T ecosystem. But it is also a potential risk, because dependency on that talent is at an all-time high, particularly in critical and emerging technology fields. And we are failing to create sufficient mechanisms to retain that talent so they can remain and work in the U.S.

Cross-sectoral collaboration will be necessary to rebuild domestic STEM education and develop the robust STEM workforce that the U.S. will need to maintain leadership in a world driven by science and technology.

We should not underestimate the scale of this problem. Improving and modernizing our highly decentralized education system is an enormous and complex task. Cross-sectoral collaboration will be necessary to rebuild domestic STEM education and develop the robust STEM workforce that the U.S. will need to maintain leadership in a world driven by science and technology.

Figure 10

International talent is essential
Fraction of US S&E workforce foreign-born by degree level



Source: National Science Board, NSF. *Science and Engineering Indicators* 2024

The New Currency of Power

If the institutions built during the Endless Frontier era have radically changed the world – to the point where the institutions themselves need to adjust to the new landscape – it's time to assess how to build for the next 75 years.

Securing U.S. S&T leadership will require new models, approaches, and institutions that embrace this changed landscape. We must recognize that today, and for the foreseeable future, science and technology is as integral to our national power, security, prosperity, and happiness as trade or military alliances. To adapt to and seize the potential of this new landscape, we must optimize cross-sectoral collaboration to draw on the strengths of all parts of our S&T ecosystem.

S&T has risen in geopolitical importance and is now an indispensable pillar of our nation's hard and soft power, national security, and economic prosperity. The success of the S&T endeavor both in the U.S. and globally has been such that science and technology is the new currency of power.

This new paradigm is a game-changer, affecting what research the U.S. prioritizes, by who and how that research is pursued and funded, how and with whom the U.S. collaborates, and the rules, ethics, and laws that govern the playing field. And it affects what it will take for the U.S. to be a global leader in S&T.

Not coincidentally, there are a lot of new restrictions, export controls, and research security reporting requirements. It impacts the time and conduct of research, so as practitioners we have to adapt to this new reality while working to ensure that the new models and policies are designed thoughtfully and fairly and preserve the openness of scientific inquiry that we know is essential to progress.

While our institutions race to perform cutting-edge research and technology development, we should also not lose sight of what Americans want and need from S&T to make their everyday lives better. And we should not assume that we know what "better" looks like.

As we develop and evolve institutions, we can design them to prioritize direct engagement and responsiveness to the American public. Let's think now about how to build inclusive new models so we can avoid public distrust in science in the future.

The success of the S&T endeavor both in the U.S. and globally has been such that this field is the new currency of power.

Build and Educate Together

CHIPS is a necessary but insufficient response to the changed landscape. In this century, scientific advancement, economic competitiveness, and national security are inextricably intertwined. And there are more S&T players along so many dimensions: nations, sectors, and demographic and geographic backgrounds.

Across all sectors, we must build and educate together and improve our models and institutions, or design new ones, so that our S&T ecosystem, and especially the federal components, can move at the speed of science and innovation and deliver societal benefits from research that Americans actually need and want. We have our work cut out for us.

First, and most obviously, as a science and policy community, we must make a clear, concerted, and sustained push to finish the job on the CHIPS & Science Act.

Of course, the elephant in the room is money. The "CHIPS" part of "CHIPS & Science" brought federal funding and industry investment together, and that encouraged further investment by state and local governments. It has fostered new partnerships and collaboration among the federal government, industry, and academia. This shows what's possible and is a potential model for future initiatives.

Through coordinated action, public and private money can be combined to compete globally and secure U.S. leadership in priority areas like semiconductors, AI, quantum, and post-genomic biology.

This model for instantiating a national strategy for S&T priorities is promising, but critical components have stalled. The failure to fund the elements related to developing STEM talent and the "Science" part of "CHIPS & Science" are serious impediments.

The current surge of private sector R&D in the U.S. will falter if our nation continues underinvesting at the federal level in both ideas and talent. If we are to be successful, we need all of CHIPS & Science, especially if we hope to replicate its model for other critical technology fields. In this changed landscape, if we want to do something big, we've got to do it together.

Opportunity: AI

The next major opportunity demanding a cross-sectoral

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approach is AI. It's a technology that's going to affect all fields and intersect with every part of the economy, including science and how it's done. It is incomplete to say that the federal government's actions alone constitute an "AI strategy."

Here's the reality: For AI, the only part of the ecosystem that's healthy, with the infrastructure and talent required to push limits, is the business sector. Even the country's very best universities have a structural problem: They can neither reproduce the state-of-the-art results that industry creates nor truly push the frontiers. They simply do not have the necessary compute power, among other tools.

The same is true of government scientists. Those of us in industry worry that hiring the best talent out of academia will leave no one left to teach the next generation. If we were talking about the role of financial institutions, we'd say that we have a market failure.

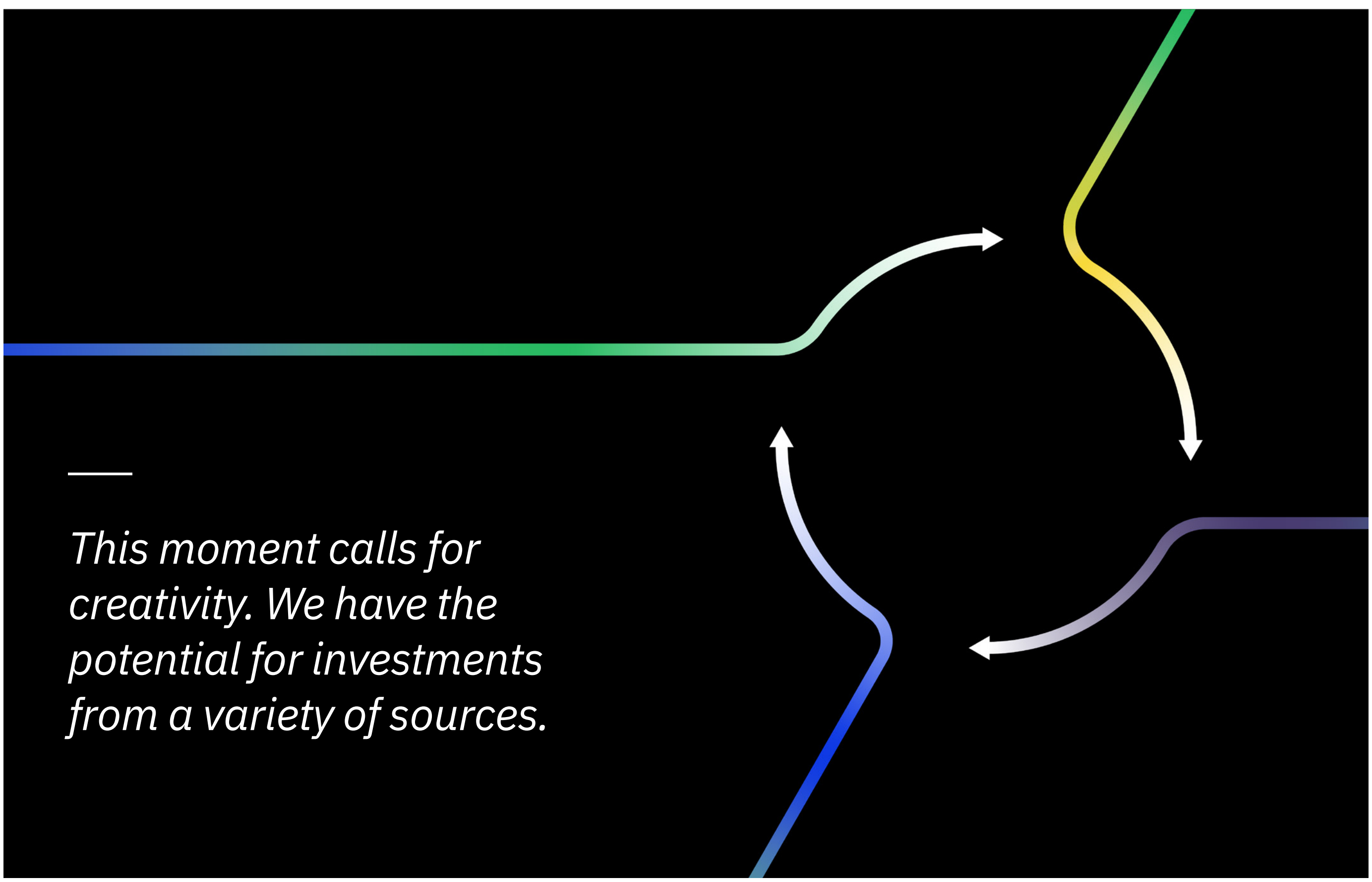
This moment calls for creativity. We have the potential for investments from a variety of sources: an AI Act, the National Artificial Intelligence Research Resource, state action, and a great deal of activity in business. But we don't know how to connect these pieces and coordinate them to achieve common goals and ensure that we are safeguarding the public interest.

Unless we have an equivalent of what's being done with semiconductors, with stacked investments and clearly defined strategies, we are going to have a serious problem with adverse impacts on our economic competitiveness, our national security, and perhaps even the very fabric of our society. And while federal government leadership is indispensable, it cannot single-handedly solve this problem.

Next, we must inspire our fellow Americans with the promise of S&T and translate that inspiration into participation by attracting and retaining domestic talent from every demographic and every corner of the country and connecting them via vibrant STEM education and fulfilling careers.

As previous NSB Chair Dan Reed testified when he went before Congress this past spring, "It's time – in fact, well past time – for a National Defense Education Act 2.0 that would inspire and enable a new generation to participate in S&T."

The return on that investment would be huge for both the country and for individuals. And it is both ethical and prudent to ensure we are not leaving large segments of our population or regions of the country behind.



A Call to Action

The future success of our R&D ecosystem will also depend on our ability to quickly coordinate and align our S&T activities across sectors and keep pace with the speed of scientific and technological advances.

We need to design and execute a cross-sectoral national S&T strategy. Our decentralized system facilitates creativity and resilience but also has inefficiencies. The radical changes in the R&D landscape call for a new approach to federal stewardship of our S&T ecosystem that maintains the benefits of our distributed system while still positioning our nation for success. This may require not just improving existing institutions but building new ones.

Furthermore, we need to develop the tools within each federal agency that will enable this cross-sectoral R&D collaboration. An example is NSF's directorate for Technology, Innovation, and Partnerships, or TIP. This is the Foundation's first new directorate in 30 years. It aims to drive regional innovation, bring new participants to the table, and sustain connections across sectors. This is the kind of new model that agencies need to be able to create, leveraging federal investments to complement activities and research in the private sector. This is part of the "and Science" that we need to follow through on because we're going to need the resources and commitment to scale and land it.

This is a call to action. There are many open questions we need to explore:

Will evolving our existing institutions be enough, or should we create new structures and institutions to better enable cross-sectoral collaboration and activities?

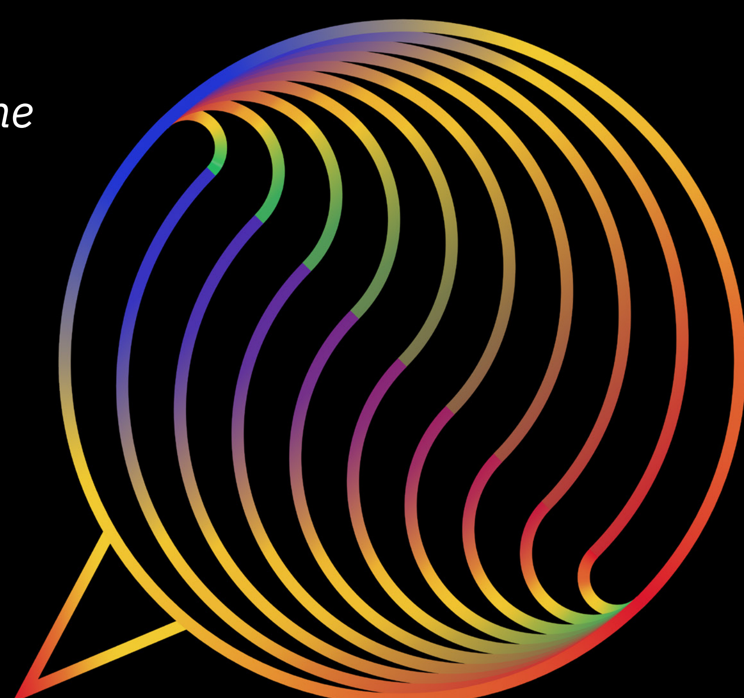
How should we approach international engagements? What is the G7 or G20 of technology? Do we need a NATO for S&T?

Should we lean into continued but selective collaboration with China on basic and open science to stay true to our values about open scientific inquiry and to avoid technological surprise?

How can we mobilize all of the U.S.'s assets to address the nation's persistent challenges in STEM education?

How can we use the 75th anniversary of NSF as an opportunity to

The radical changes in the R&D landscape call for a new approach to federal stewardship of our S&T ecosystem.



engage with our stakeholders to think together about how to evolve the agency to be even more successful in its next 75 years?

There's no less opportunity now than there was at the beginning of this journey 75 years ago. Within the NSB we have begun thinking about how we can educate and build together across sectors. Those of us in the science and technology community are starting to learn and figure out the ingredients for success in an era of Connected Horizons. For example, National Academy of Sciences President Marcia McNutt calls attention to the changed landscape in her editorial Keeping America "Science Strong." We must invent the right models and the right institutions. We must try new experiments and build and scale for success.

The changed landscape is not a bad picture. It's a different picture, a new picture. It is a landscape full of promise if we can figure out how to capitalize on its advantages and strengths.

It is not a moment to wish to turn back the clock. It is a moment to keep our eyes on the future.

Even as we celebrate NSF's 75th anniversary, let's lay the groundwork for the next 75. This effort will take all of us, finding new ways to educate and build together.

Watch the entire recording of the National Science Board 490th Meeting

www.youtube.com/watch?v=DVtbQLYJBY0

Let's work together, connecting across not a single frontier but many horizons, to deliver on the promise of science and technology for our nation and for humanity. ■

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