Testimony of
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Upgrading the Future: Realizing Better Dreams

Better Futures Start with Better Dreams

Chairman Lucas, Ranking Member Lofgren, and members of the committee, it is a privilege to testify before you. On behalf of myself and my 23 National Science Board colleagues, I thank you for the *CHIPS & Science Act* and its bold blueprint for a better, brighter future for science and engineering (S&E) in the United States. Fully funding the Administration's FY24 budget request for the National Science Foundation (NSF) advances the *CHIPS and Science Act* and is essential to our nation's global leadership in STEM. The FY24 budget request furthers NSF's original mission, which was inspired by renowned scientific and engineering visionary Vannevar Bush, who believed the core rationale for federal investment in research and talent development was to address pragmatic and important societal priorities: national security, economic well-being, and public health. At the end of World War II, the compelling rationale for federal research investment was to further the country's interests and address its needs. It still is.

Neal Stephenson, one of my favorite science fiction writers, wrote that "if we want to create a better future, we need to start with better dreams." The *CHIPS & Science Act* is the stuff of better dreams and better futures for U.S. S&T. We must own our destiny and respond accordingly. My testimony today underscores that the passage of *CHIPS & Science* was just the beginning. There is an urgent need to turn the dreams of the Act's science provisions into actual futures through appropriations. It is unrealistic to believe we can reverse our current trajectory – one that has us losing to China – without making substantial new federal investments in the foundational – basic and applied – elements of our S&E ecosystem: talent development and cultivation, use-inspired research and translation, research infrastructure, and curiosity-driven research. To that end, I believe it is imperative that Congress fully funds the President's FY24 budget request for NSF.

I come before you at a critical juncture for our nation and our S&E enterprise. We face a global landscape in which other nations are challenging our country's geopolitical influence on a scale that we have not seen since the Cold War. At the same time, once unquestioned U.S. global leadership in science and technology is in peril, and in some key domains we have already been eclipsed. Preserving our leadership in science and technology is inextricably linked with preserving our national security. Military strength is derived from economic strength, and economic strength is driven by a robust and relentless cycle of discovery and innovation. Thus, science funding – like defense funding – is and ought to be treated as a non-negotiable federal investment.

Let me be very clear. While we continue to debate and dither, the time for concerted action to reinvest in our S&E enterprise grows ever shorter and the stakes grow ever higher. Having watched and learned, other countries have been investing heavily in their own innovation ecosystems, cultivating human talent, expanding their knowledge workforce, and constructing the advanced infrastructure needed to facilitate discovery, economic growth, and defense capabilities. These developments abroad are well documented by the NSB's Congressionally-mandated *Science & Engineering Indicators* report.

The growing challenge to U.S. pre-eminence in S&E reflects the reality that many nations now recognize that a robust S&E enterprise is critical to economic and national security. S&E industries represent a growing share of economic activity worldwide.[1] Officials from Washington to Brussels to Beijing acknowledge that leadership in critical technology fields like semiconductors, biotechnology, clean energy technology, artificial intelligence, and quantum computing and communications is a matter of national security.[2]

China has recently upped the ante. "Strengthening basic research is an urgent requirement for achieving high-level scientific and technological self-reliance [and] is the only way to build a world scientific and technological power," President Xi said earlier this year.[3] This statement came on the heels of China having already doubled spending on basic research in the last five years and having surpassed the United States in STEM degree production.[4] While the United States retains an edge in many areas of basic research, China's message is clear. It intends to go toe-to-toe with the United States by building a soup-to-nuts domestic research and development innovation engine with a large pool of homegrown talent and a sizable, sustained core of world-class basic research that continually provides new fuel for China's economy and its geopolitical ambitions.

Meanwhile, the United States is not producing enough skilled technical workers and STEM bachelor's degree holders in either the numbers or diversity needed to meet the workforce needs of the 21st century knowledge economy. Our pre-K-12 education system is failing far too many students. Too much of our manufacturing capability has been outsourced, making us overly dependent on other countries for critical elements of our economy. Our R&D enterprise is too heavily concentrated in certain geographies, leaving swaths of our country and its residents deprived of associated economic opportunities. Our technology transfer system is too slow, too unwieldy, and too inefficient to compete with an integrated nation state like China.

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[1] https://ncses.nsf.gov/pubs/nsb20226/global-trade-in-knowledge-and-technology-intensive-output

[2] https://www.whitehouse.gov/briefing-room/speeches-remarks/2022/09/16/remarks-by-national-security-advisor-jake-sullivan-at-the-special-competitive-studies-project-global-emerging-technologies-summit/; https://www.politico.com/news/2019/10/28/europe-technology-silicon-valley-059988; https://www.merics.org/en/report/comprehensive-national-security-unleashed-how-xis-approach-shapes-chinas-policies-home-and

[3] https://www.science.org/content/article/china-rolls-out-radical-change-its-research-enterprise

[4] https://www.science.org/content/article/china-rolls-out-radical-change-its-research-enterprise

Fortunately, the *CHIPS & Science Act* recognized that for the United States to retain its S&E leadership, it must strengthen and adapt its S&E enterprise. *The CHIPS and Science Act* includes essential provisions to build the larger and more inclusive STEM workforce at all education levels that we so desperately need, expand the geography of innovative economic activity, and speed the translation of basic research conducted in the United States into products, goods, and services. In addition, through its requirements for an Office of Science and Technology Policy (OSTP)-led Quadrennial Review and greater cross-agency and cross-sector partnerships, the *Act* provides a framework for tighter coordination among government, industry, and educational institutions so that our innovation engine can work faster and more effectively. Acknowledging that new resources are needed to do all of this, *The CHIPS and Science Act* also lays out authorization levels that would provide a significant and much-needed infusion of federal investment across the nation's science agencies.

The Need for a Coherent U.S. S&E Strategy

"Where there is no vision, the people perish." – Proverbs

To compete in this changing global S&E environment, we need a more coherent, strategic plan for U.S. S&E. To be clear, I am not calling for a top-down government plan, with all its attendant bureaucratic burdens, but rather one that lays out the key components our system needs and engenders and incentivizes a cross-sectoral approach that rewards systems thinking and unleashes and empowers American innovation. I hope the upcoming Quadrennial Review moves the nation in this direction. NSB is eager to partner with OSTP on this project.

Our S&E ecosystem is greatly enriched by distributed, independent contributions from industry, academia, and government, but it can also be hampered by choices that benefit specific contexts to the detriment of the overall enterprise. Designing new technologies in the United States and then outsourcing their manufacturing to other countries may reduce labor costs and free companies and investors from onerous capital requirements, but it comes with systemic risks for the U.S. economy and our national security.

One such systemic risk, which stemmed from the offshoring of semiconductor fabrication, materialized during the pandemic. The resulting disruption of the global semiconductor supply chain created shortages that affected a wide range of other industries, including those critical to national defense. Belatedly and at great expense, we are now trying to reshore semiconductor manufacturing. As a nation, we need to be more strategic and systemic in risk assessment and management in other critical technology fields. Put another way, a group of locally effective choices does not always lead to a nationally effective strategy.

The same systemic risks exist for our advanced STEM workforce. Recruiting international STEM talent with better K-12 preparation in mathematics and science – to both academia and industry – is often cheaper and quicker than educating and training domestic talent. The result, long tracked by the NSB, is that we are now critically dependent on attracting and retaining international students, especially those pursuing or with advanced degrees in critical technology fields.[5] Meanwhile, both the numbers and diversity of our domestic STEM talent base remain far too small.

Make no mistake, we want and need the best and brightest STEM talent from around the world. Only by attracting and retaining such talent can we continue to create an environment in which the United States retains its competitive advantage. After all, the history of intellectual, cultural, and economic contributions by immigrants to the United States is extraordinary; it is one of our country's enduring "superpowers," that we welcome and embrace talent, regardless of country of origin. That said, our current level of dependence on this talent renders us vulnerable. Our continued ability to attract international STEM talent is not a given; other nations are providing increasingly attractive alternatives for globally mobile talent.[6]

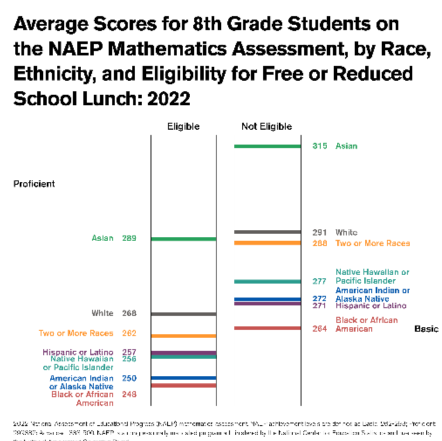
Perhaps it is not surprising, given that I am a computer scientist, that I think about our S&E ecosystem as an operating system. As we have become more complacent as a nation in our approach to S&E, we have resorted to patching "holes" in our operating system code. This is a risky strategy; fixing one piece of code can break another, and a multitude of patches creates a brittle system, making it difficult to add desirable new features.

Simply put, we are running a patched, 20th century innovation ecosystem in a 21st century world. We need to upgrade our entire operating system: expanding and diversifying the STEM talent pipeline, accelerating the delivery of research benefits, upgrading our research infrastructure, and elevating our commitment to basic research. This is why federal funding is so important. Only the federal government can create and nurture these foundational aspects that matter to all sectors.

Operating System Element: Talent Upgrade

> "I cannot distinctly remember a time when I did not think that a scientist was the most exciting possible thing to be." – Peter Medawar

For too long, we have failed to build and sustain the domestic STEM talent pipeline needed to feed the 21st century knowledge economy, and we now face a pre-K-12 STEM education crisis. Too many of our primary and secondary school STEM students are being left behind, and the leaky pipeline dwindles further in college and graduate school. As a result, we are failing to develop, attract, and expand the diverse STEM talent base – at all educational levels – necessary for U.S. S&E leadership.



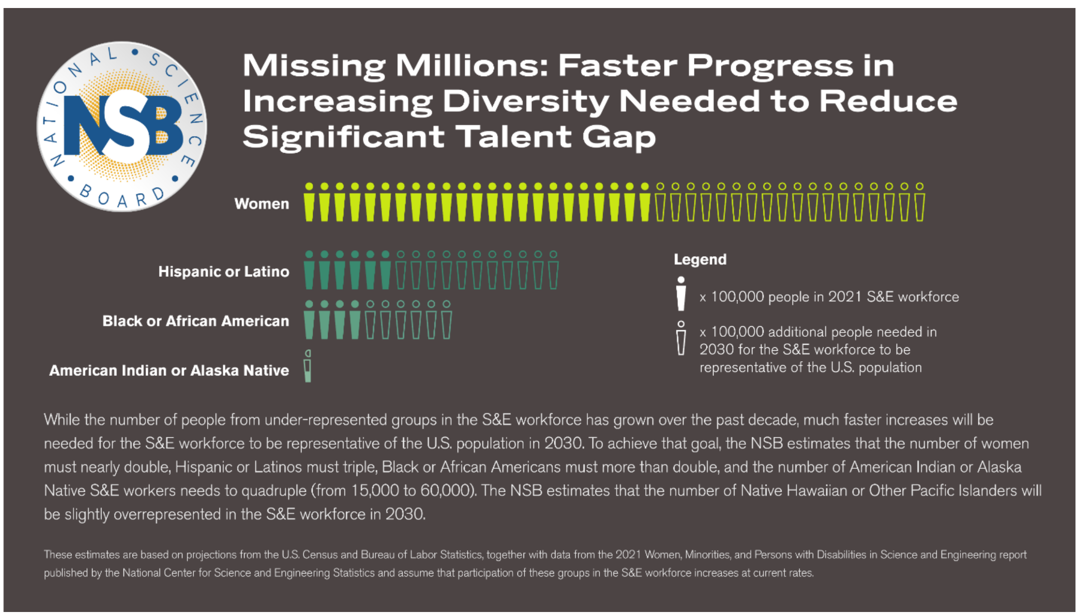
STEM preparation in elementary and secondary school is foundational; the data show that students who do not perform at grade level in mathematics in 8th grade do not go on to study STEM in college. This crippling situation is far more acute for students from lower socioeconomic

[5] https://www.nsf.gov/nsb/sei/one-pagers/NSB-International-STEM-Talent-2022.pdf
[6] https://www.nsf.gov/pubs/2020/nsb20222/nsb20222.pdf

standing or underrepresented backgrounds. On average, U.S. 8th grade students of all ethnicities who are eligible for free or reduced school lunches fail to achieve mathematics proficiency, but the disparity is most pronounced for Black, Hispanic, Native Hawaiian or Pacific Islander, and American Indian or Alaska Native students.[7]

The pandemic compounded these disparities. The most recent National Assessment of Educational Progress showed the largest decline in reading skills since 1990 and the first ever decline in mathematics.[8] Worse, this disruption has exacerbated disparities in math education across the nation. Although all students saw a decline in test scores, the worst performing students saw their test scores drop four times more than the best; Black students' scores decreased more than twice that of white students.[9] STEM post-secondary education is also struggling. The pandemic saw undergraduate enrollment drop by 3.6% in the fall of 2020.[10] Public community colleges, an important pathway for many low socio-economic status and minority students into STEM and for developing the skilled technical workforce, had the sharpest decline (10.1%).[11] Higher proportions of Blacks and Hispanics than of Whites reported that their postsecondary education plans were canceled, whereas higher proportions of Whites than of Blacks or Hispanics reported that they had to take classes in different formats.[12]

These troubling developments come at a time when the nation's demographics are shifting. For our STEM workforce to be representative of the U.S. population in 2030, the number of women must nearly double, Hispanic or Latinos must triple, Black or African Americans must more than double, and the number of American Indian or Alaska Natives must quadruple.



[7] https://ncses.nsf.gov/pubs/nsb20196/student-learning-in-mathematics-and-science#tableCtr1533
[8] https://www.nationsreportcard.gov/highlights/ltt/2022/
[9] https://www.nationsreportcard.gov/highlights/ltt/2022/
[10] https://www.nsf.gov/nsb/news/news_summ.jsp?cntn_id=304497
[11] https://www.nsf.gov/nsb/news/news_summ.jsp?cntn_id=304497
[12] https://ncses.nsf.gov/pubs/nsb20223/u-s-institutions-providing-s-e-higher-education

These "missing millions," as the NSB's *Vision 2030* report highlighted, are an untapped talent base we can ill-afford to lose.[13] We are leaving an extraordinary number of Americans sitting on the sidelines of our S&E enterprise precisely when employers need more domestic STEM talent at all education levels. Failure to cultivate the missing millions – including individuals with fewer socioeconomic resources and individuals in rural communities – is also a failure to enable individual economic opportunity. The NSB has long observed that an increasing fraction of all jobs require critical thinking, technical knowledge, and mathematical reasoning and that STEM jobs are generally both better paid than comparable jobs at the same educational level and more resilient to economic downturns.[14]

We must also address pressing challenges in post-secondary education that limit our ability to develop domestic STEM talent. We need to encourage colleges to continue to reevaluate their educational approaches, making curricula relevant and meeting interested students where they are. We also need to do more to make public higher education more affordable and graduate work in STEM fields more financially viable.

Although I sit before you as Chair of the National Science Board, as a former corporate officer at Microsoft, and as a professor of computational science at the University of Utah, 48 years ago I was a poor, first-generation college student from the Arkansas Ozarks.

I was fortunate to attend university thanks to a combination of academic scholarships, a Basic Educational Opportunity Grant (now Pell) for low-income students, and a small amount of money I saved from working summer jobs. I lived like a pauper, with a social life limited by finances to free lectures and cultural events, and my wallet was empty, save for my student ID card and a driver's license. The latter seemed superfluous because I could not afford a car.

Nevertheless, I completed both undergraduate and graduate degrees in computer science – a field now integral to our scientific enterprise, our economic security, and our national security – without any student debt. While I am extraordinarily grateful for the opportunities, I am also alarmed that it is increasingly clear my educational path is no longer widely available.

Undergraduate tuition at a state university in the 1970s was just a few hundred dollars per year. Today, it exceeds $10,000 a year, with comparable student room and board costs.[15] A four-year college degree at a public university can cost substantially more than $100,000, while the maximum Pell grant is under $7,000 and just recently increased by $500. These economic challenges extend to graduate education as well. Too many of our STEM students in graduate school face years of penury, living at or below the poverty line.

Talent arises everywhere, regardless of culture or family socioeconomic or generational status. Countries that identify, nurture, and cultivate that talent – as the United States did in my case – are the ones that will continue to lead the global race in research and innovation.

The NSF has a critical role to play in addressing our STEM talent crisis. As the nation's STEM talent agency, it is helping underrepresented students find pathways toward STEM careers through targeted

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[13] https://www.nsf.gov/nsb/publications/2020/nsb202015.pdf
[14] https://www.nsf.gov/pubs/2015/nsb201510/nsb201510.pdf
[15] https://research.collegeboard.org/media/pdf/trends-in-college-pricing-student-aid-2022.pdf

undergraduate and graduate education programs, including those that aid minority serving institutions. The agency is also developing skilled technical workers through its Advanced Technological Education Program, which supports partnerships among two-year institutions of higher education, colleges and universities, industry, and others to develop technicians in science and engineering. NSF is also forging partnerships with other agencies via programs such as REU-ASSURE, the joint NSF-Department of Defense program that supports undergraduate research in DoD-relevant disciplines, preparing them for the national security workforce.

NSF's FY24 budget request emphasizes efforts to broaden domestic participation in STEM education and turn STEM career dreams into realities. I urge you to fully fund the talent efforts in the Administration's NSF FY24 Budget Request, while acknowledging that the NSF and the nation must do much more to cultivate domestic STEM talent. Based on historical rates of change, current federally-funded programs and approaches across the government will not address either the inadequate numbers nor the missing diversity in the domestic STEM workforce – the *missing millions* – on a timescale consistent with national needs.

We cannot neglect these workforce and education challenges any longer. Educated and empowered talent is the treasure on which any nation's prosperity, health, and security depend. In the late 1950s and early 1960s, in the wake of Sputnik, the United States invested heavily not only in S&E fields but also in developing domestic talent. The National Defense Education Act (NDEA) was transformative; it galvanized higher education to produce more STEM graduates in areas critical to national security.

NSB is laser focused on talent. Inspired by the idea of a NDEA for the 21st century, we look forward to engaging with you in the months ahead on recommendations to meet our urgent domestic talent needs.

Operating System Element: Delivering Benefits from Research

"Genius is one percent inspiration and 99 percent perspiration." – Thomas Edison

For the United States to compete and win in today's S&E environment, we must enhance our ability to rapidly deliver benefits from research. While the U.S.'s decentralized, bottom-up approach to S&E research produces new knowledge in many disciplines, too often nascent discoveries struggle to cross the "valley of death" from the research environment to industry uptake. I have seen this firsthand from both sides, as a Vice President for Research and Economic Development at the University of Iowa and as a Corporate Vice President at Microsoft.

NSF's new Directorate for Technology, Innovation and Partnerships (TIP) is an essential addition to the nation's S&E ecosystem. It will help speed the path from discovery to innovation here in the United States via greater NSF investment in use-inspired research and translation activities, building institutional and regional capacity to engage in innovative activity, and enhancing the partnerships among academia, government, and industry that are needed to do so.

NSB is grateful for the trust the *CHIPS & Science Act* placed in NSF in authorizing this new directorate. However, the promise of TIP cannot be realized without continued and substantial budget growth. In FY23, the agency prioritized allocating new resources to TIP, funding it at the President's FY23 request level. TIP will need additional investment in FY24 and beyond. My NSB colleagues and I remain concerned that without continued robust budget growth, the TIP directorate will be too small to carry out the mission entrusted to it.

As NSF's first new directorate in over three decades, TIP marks a sizable shift in the agency's culture. The Board is closely monitoring this undertaking and helping shape the directorate's strategy via guidance and oversight. Our messages to NSF have been clear and focused: (1) the new directorate has different objectives than other directorates and will be judged by economic outcome metrics – jobs created and geographic regions strengthened, and (2) the agency must demonstrate synergies between TIP and other NSF directorates. Just as basic research in NSF's other directorates fuel TIP, so too should TIP lead to new basic research questions pursued in the other directorates. Via this feedback loop, NSF can amplify the value of having curiosity-driven, use-inspired, and translational research in its portfolio, fulfilling Vannevar Bush's seminal vision.

In its first year, the TIP directorate launched its signature Regional Innovation Engines (Engines) program. The Engines program develops regional coalitions to conduct use-inspired research and drive those results to market, stimulating job creation and economic growth. NSF saw strong demand for this program from across the entire country. Thanks to the budget increase in FY23, later this year, NSF will be able to make some full-fledged Engine awards of up to $160M each for up to 10 years.

The Engines program is exactly the kind of intentional, systemic effort our innovation ecosystem's operating system needs. It takes a cross-sectoral approach, focuses on building sustainable regional ecosystems (technology and talent), and addresses pressing national needs to speed up the innovation cycle, and expands the geography of innovation to regions of the country that are poised to support S&E industries.

NSF is complementing the Engines program with a suite of related programs, including Enabling Partnerships to Increase Innovation Capacity, Experiential Learning for Emerging and Novel Technologies, Accelerating Research Translation, and the Entrepreneurial Fellowship Program.

Funding TIP at the FY 24 Request Level would permit NSF to continue to scale up the Engines program, regionalize NSF's Convergence Accelerator program, and start a program to support test beds to advance development, operation, integration, deployment and demonstration of innovative technologies.

The NSB's and NSF's commitment to delivering benefits from research goes beyond TIP. In the last decade, the agency has shifted policies to enhance research in the national interest, while increasing accountability and transparency. For over two decades, NSF has also used a broader impacts criterion in its Merit Review process. At the NSB's February 2023 meeting, the NSB authorized the creation of a commission to re-examine NSF's Merit Review criteria. This re-examination, the first in over a decade, is motivated, in part, by a desire to consider how the merit review criteria might be modified to further enhance NSF's emphasis on delivering benefits from research.

Operating System Element: Research Infrastructure

"Nothing tends so much to the advancement of new knowledge as the application of a new instrument."
– Humphry Davy

Research infrastructure — including major research facilities, mid-scale research infrastructure, major research instrumentation, and cyberinfrastructure – enables discovery and innovation. Beamlines permit researchers to explore different materials, cryo-electron microscopy enables probing of biological samples, test beds support new product development in critical technology areas, and computing now underpins so much of science that the very phrase "computational science" is now rhetorically redundant. Our investments in research infrastructure can also lead to unanticipated spillover economic benefits; the technical feat associated with constructing NSF's Laser Interferometer Gravitational Wave Detector (LIGO) pushed the limits of existing technology, spawning breakthroughs that led to spin-off technologies in optics, lasers, and distributed computing.[16]

Just as talent is needed to compete globally in S&E, so too, is research infrastructure. Equally importantly, the two are linked. The world's best STEM talent flows to where the best scientific tools are located. For the U.S. S&E enterprise to remain a global leader, we need to continually invest in the facilities and tools that enable research and development (R&D) and that attract globally mobile talent to the United States.

Now, more than ever, the United States needs a coordinated national strategy for major federally funded research facilities and infrastructure. Major research facilities such as research vessels, telescopes, and gravitational wave detectors represent substantial decades-long financial commitments and need predictable, long-term funding. The cost of designing, constructing, and operating these facilities continues to grow; design and construction alone is now well north of $1 billion for major research facilities in physics and astronomy. Increasingly, this cost threshold exceeds what a single agency or even a single nation can afford alone. Despite rising costs, as a country, we must choose wisely and invest appropriately to ensure continued global leadership.

At the same time, we cannot afford to pursue frontier-class, next generation major research facilities to the exclusion of other types of research infrastructure. Scientific infrastructure at all scales is essential to U.S. competitiveness in S&E. Investments in major research instrumentation, mid-scale research infrastructure, and cyberinfrastructure, which can be more readily distributed across the country to serve as tools for researchers in various regions, are also critical to expanding the geography of innovation and building a more inclusive research enterprise through greater access to such tools.

I hope that the Quadrennial Review can facilitate such a coordinated national approach – one that looks across federal agencies to ensure that the United States' research infrastructure investments are strategic, complementary, and second-to-none. Being second-to-none means investing smartly rather than investing in everything. As part of this process, we must take a hard look at areas where we as a country need – for reasons of economic or national security – to go it alone. We must also identify areas where our dollars would go further by investing in shared facilities in cooperation with like-minded nations.

[16] https://www.ligo.caltech.edu/page/science-impact

NSF's FY24 budget request balances a robust portfolio of facilities and infrastructure at multiple scales with awards to the researchers who depend on the observations and data they produce. The FY24 request for the Major Research Equipment and Facilities Construction (MREFC) account supports several important infrastructure projects, including the construction of the Leadership Class Computing Facility (LCCF) and Track 2 of the Mid-scale Research Infrastructure Program.

The global race of technological leadership, whether in semiconductors or in computing, continues unabated. Europe, Japan, and China are all designing and deploying ever larger advanced computing systems. Moreover, advanced Artificial Intelligence (AI) systems such as GPT-4 depend on large-scale computing platforms for their training and use. Absent access to advanced computing in academia, the "brain drain" of AI researchers from academia to industry will continue, making it harder to train the next generation of talent and realize the collaborative vision of the National AI Research Task Force.

In that spirit, the LCCF will provide unique and powerful computational and data analytics capabilities, as well as critical software and services, for the nation's researchers. In addition to large-scale computational models, the LCCF will also support urgent computing, where immediate access to computing resources and real-time data facilitates emergency response scenarios. Echoing the consistent theme of workforce development, the LCCF will also offer education and outreach activities to nurture our nation's future science and engineering workforce in data and computational science.

As important as big instruments are to innovation and discovery, they are not enough. As the Board stated in its 2018 report, "Bridging the Gap: Building a Sustained Approach to Mid-scale Research Infrastructure and Cyberinfrastructure at NSF," gaps in agency support of mid-scale research infrastructure also put future areas of U.S. science and engineering research at risk. Investing in research instruments and capabilities of more modest financial size can expand the types of research possible, lay the groundwork for building the next generation of major facilities, and build capacity in EPSCOR jurisdictions.

The Board is pleased to see continued strong demand for the second portfolio of Mid-scale Track 2 awards. In the years since its initiation, the Mid-scale Research Infrastructure program has engaged institutions in 30 states and territories, including many EPSCoR states. Such regional investment can catalyze research across a range of institutional types and diversify our science and engineering S&E enterprise.

Operating System Element: Basic Research

"Basic research is performed without thought of practical ends. It results in general knowledge and understanding of nature and its laws." – Vannevar Bush, *Science the Endless Frontier*

In the 78 years since Bush first crafted that sentence, the federal government has been instrumental to U.S. leadership in basic research – curiosity or use-inspired research undertaken before it had any known application. For the past 73 years, NSF has been privileged to be at the center of this essential effort, investing in basic research across all fields of science and engineering that fuel our innovation ecosystem, strengthening our economic and national security, and paving the way for products, services, and technologies that are now so ubiquitous that we have come to take them for granted. NSF's central mission is to invest across S&E fields, monitor what is emerging, and cultivate the *next,*

next big things in S&E. This often leads to exciting outcomes that could not have been anticipated at the time of initial NSF investment.

Take GPT-4, for example. This artificial intelligence (AI) chatbot has taken the world by storm since its launch a few months ago, and it and other AI tools are changing how we do science and, more broadly, how people approach their work and their leisure. Researchers can now use AI to predict the shape of proteins, readily identify diseases in plants, design parts for spaceships, and summarize academic articles.[17] Companies are already using GPT-4 and other AI tools to accelerate development of new software, translate documents, and assist with a wide variety of business tasks. Today's increasingly sophisticated AI tools are now possible because of decades of government investment, principally through NSF and the Defense Advanced Research Projects Agency (DARPA).

The story of NSF's decades long support for what has become AI illustrates how NSF helps cultivate new fields of research. Initially NSF followed researchers' interests in understanding computer-human interfaces, funding early research grants in machine learning, natural language processing, robotics, and computer vision. As promising areas emerged, NSF cultivated those areas via additional research grants and catalyzed further research by sponsoring meetings that pushed this research forward. As the potential for AI to be the next, next big thing became clear, NSF further scaled its investments by creating AI Research Institutes. These institutes have come to focus on long-term, high-reward AI research and have increasingly brought in partners from across the government and the private sector, paving the way for promising technology to make it to the marketplace. Leveraging these basic research investments and the talent pool they created, U.S. industry invested heavily in the infrastructure and people needed to bring products to market. Because of its longstanding cultivation of this field, NSF is now a leader in AI planning and activities across the federal government.

As this success story illustrates, much basic research – including early research in AI – begins with a driving curiosity about the unknown, then the derivatives of the basic research drive a vital part of our economy, with business R&D leveraging these intellectual insights. Today's R&D-intensive industries exist, in part, because of federal government investments – long before the research had a known application.

Troublingly, although overall funding of R&D in the U.S. continues to rise, the share of basic research that the federal government funds is declining. This matters because while businesses are investing more in basic research, they tend to invest in just a few areas that have a high potential to lead to new or improved technologies in the near-term, such as computing and pharmaceuticals, not in areas where the potential payoff is uncertain and may be years away.

Only the federal government can take the kinds of strategic risks to invest long-term across the sciences and fuel new knowledge with potentially big returns for the country. China's announcement that it is ramping up its investment in basic research, is in fact, a tacit acknowledgement that government investment in basic research is necessary and that the United States has had the right strategy in this regard all along.

Even as the United States and NSF increase their emphasis on directed research related to critical technologies and societal challenges and make new investments to speed the translation of existing basic research, the United States cannot afford to rest on its laurels when it comes to investing in

[17] "35 Ways Real People Are Using A.I. Right Now," *New York Times,* April 14, 2023.

totality of the basic research enterprise. To ensure that the significant share of the scientific breakthroughs and innovations that will shape our global future are “Made in America,” we need to translate the blueprint of the *CHIPS and Science Act* into a fully funded, end-to-end action plan that also increases investment in basic research.

Conclusion: Upgrading the OS

“You are either the market leader, a viable number two, or road kill. You don’t want to be road kill.” – Tom Siebel

In the nine months since the passage of *CHIPS & Science,* NSF has begun implementation of the Act’s guidance. In addition to launching several new TIP directorate programs and beginning to implement the semiconductor education and workforce provisions that were funded by CHIPS, NSF has also moved to establish the Office of the Chief of Research Security Strategy and Policy (OCRSSP) and the Research Security Integrity Information Sharing and Analysis Organization, commissioned five required studies, and issued updated solicitations and Dear Colleague Letters that reflect *CHIPS and Science*-mandated changes to cost sharing for Major Research Infrastructure (MRI) awards and Noyce Fellowships. The Board appreciates the trust that you have placed in NSF to lead on so many dimensions of this legislation. The NSB is committed to working with NSF to pursue every possible mechanism — both policy and process — to make existing NSF dollars further the objectives of *CHIPS & Science*. As the FY24 Budget Request attests, the agency has much more planned for FY24.

In an increasingly uncertain world, the U.S. now finds itself facing new challenges; it’s not the first time, nor will it be the last. Our continued prosperity and national security depend on the vitality and global leadership of the nation’s S&E enterprise. Vannevar Bush recognized this seven decades ago, at the end of World War II. In a global economy driven by scientific discovery and technological innovation, it is even more true today.

As an initial blueprint for a better future, we must fully fund the provisions of the *CHIPS and Science Act*. However, that alone will not be enough. We also need a clear and coherent federal S&E strategy that maximizes our current resources (both intra-agency and inter-agency) while also committing the additional resources needed to secure our continued global leadership. China is moving ahead, and absent further action, it is not a question of *if* but *when* the United States loses its leadership in S&E.

As stewards of the present, the future is in our hands. Let the historians and policy analysts, but most of all – our children and grandchildren – mark this as the time we not only embraced better dreams, but we put aside our differences, embraced our common goal, and acted with compelling vision and unwavering resolution to make those dreams a future and better reality for the country and for the world.