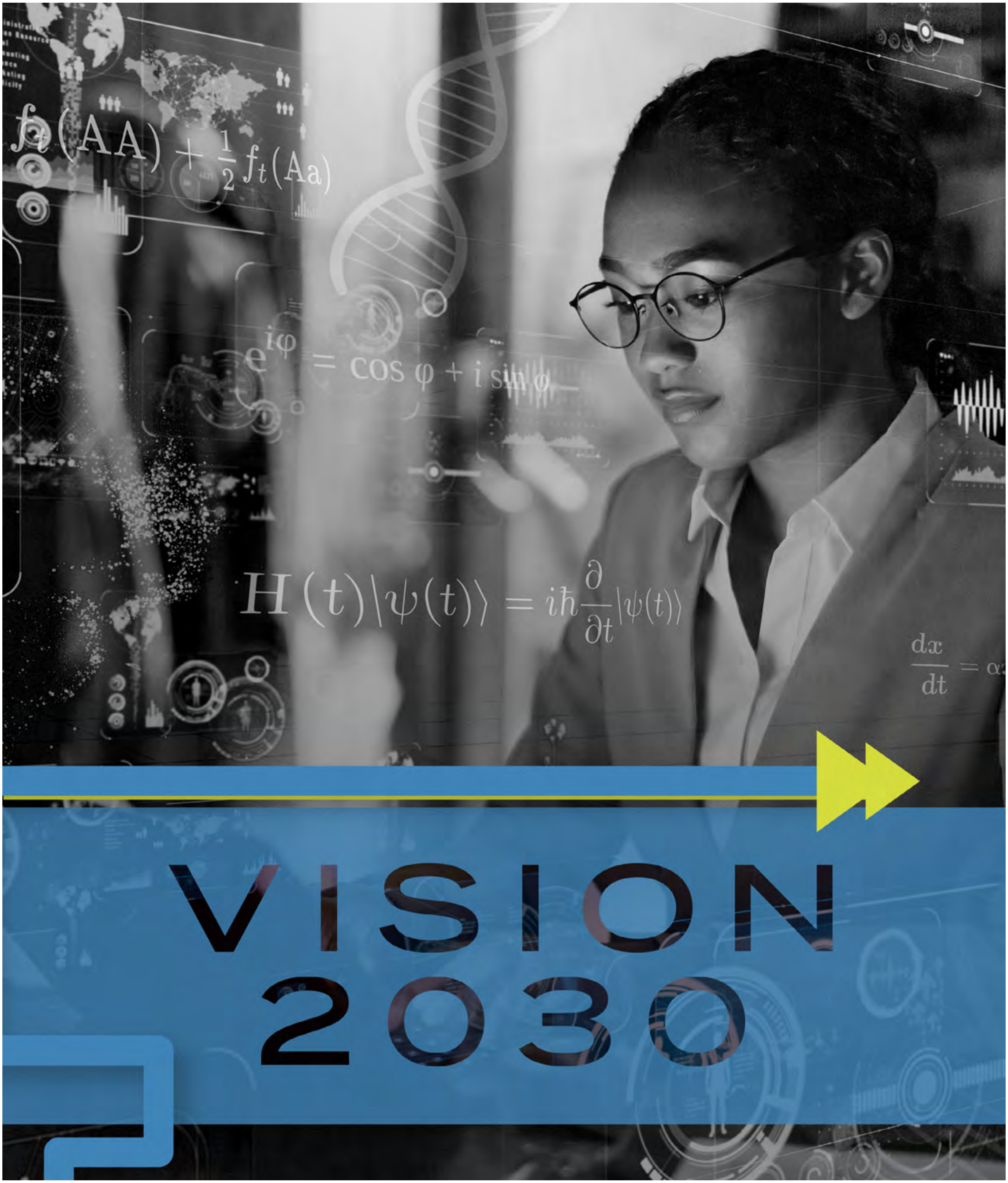
NATIONAL SCIENCE BOARD



VISION 2030

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The U.S. has made the investments needed to fuel an innovation economy and remain preeminent in science and engineering.

The U.S. remains a magnet for the world's best talent.

U.S. scientists and engineers are modeling scientific values that are practiced throughout the world.

The U.S. has increased STEM skills in its workforce, creating more opportunities for all Americans.

The U.S. has created an accessible, attractive S&E enterprise that more closely reflects the nation's demographic and geographic diversity.

U.S. government, industry, and academic partners are working in coordination to realize national R&D priorities and accelerate the discovery-to-innovation cycle.

NSF continues to drive U.S innovation through fundamental research and lead the evolution of the global practice of science and engineering.

VISION FOR THE FUTURE

This report lays out what the National Science Board believes the U.S. must do to achieve this vision and remain the world innovation leader in 2030.

A CASE FOR URGENCY

United States (U.S.) leadership in science and engineering (S&E) has shaped Americans' way of life for seven decades, contributing to the nation's economic prosperity and ensuring its national security. The **U.S. S&E ecosystem,** built on federally funded fundamental research, has led to innovation and new industries, revolutionized health care, promoted peace, created the mobile digital world, and transformed nearly every aspect of Americans' lives.

Today, science continues to be the endless frontier, but U.S. researchers are not the only explorers. Science and engineering – particularly fundamental research conducted transparently and openly – benefits the entire world. Yet if the U.S. is to ensure a strong economy and national security, it is vital that a significant share of future scientific breakthroughs and world-changing innovations be made here. In this new era, the National Science Board (Board, NSB) sees three trends that threaten the nation's S&E leadership.

GLOBALIZATION OF S&E

S&E is now a truly worldwide enterprise, with more players and opportunities, from which humanity's collective knowledge is growing rapidly. This dynamic research and development (R&D) landscape is characterized by interdependence as well as competition. While the U.S. S&E enterprise continues to grow in absolute terms, the data show that the global S&E enterprise is growing faster and consequently the U.S. share of discovery is dropping (see Figure 1). The U.S., which led the world in total R&D investment for decades, likely ceded this status to China in 2019. If these trends continue, NSB projects that China will invest over $200 billion a year more in R&D than the U.S. by 2030. A bright spot amongst these concerning trends is that the U.S. has a significant lead in fundamental research – the seed corn for America's entire S&E enterprise.[1]

KEY QUESTION: *How can America keep its lead in fundamental research?*

GROWTH OF KNOWLEDGE- AND TECHNOLOGY-INTENSIVE INDUSTRIES

Global R&D investments have tripled since 2000, reflecting increased activity and competition in knowledge- and technology-intensive industries.[2] In the U.S. such industries account for 17% of Gross Domestic Product and generate $2.7 trillion in output, outpacing any other sector.[3] Today's R&D intensive industries exist, in part, because of discoveries arising from basic research that the federal government funded decades ago, well before the research had a known application. Although inflation-adjusted federal basic research expenditures are only slightly lower in 2017 than in 2000,[4] the share of basic research that is federally funded declined from 58% to 42% during that period. Basic research across all fields of S&E, performed primarily at colleges and universities and funded by federal investments, is an important innovation engine that fuels subsequent research across the S&E ecosystem, by both private industry and mission-oriented agencies such as NASA and the Department of Defense.

KEY QUESTION: *How can American discoveries continue to empower U.S. businesses and entrepreneurs to succeed globally?*

DEMAND FOR STEM TALENT

Worldwide demand for STEM-capable (Science, Technology, Engineering, and Mathematics) workers keeps growing, driven by international opportunities and competition, and by rapid increases in the number of jobs that require STEM skills, including in lines of work that historically did not require S&E knowledge. This situation will only become more urgent: by 2026, S&E jobs are predicted to grow by 13% compared with 7% growth in the overall U.S. workforce.[5] Yet even as STEM competencies have become more essential, U.S. K-12 mathematics and science scores are well below those of many other nations and have stagnated.[6] Women and underrepresented minorities remain inadequately represented in S&E relative to their proportions in the U.S. population. The rapid growth of S&E jobs and demographic changes have outpaced the progress that has been made in the participation of these groups in S&E.

KEY QUESTION: *How can the U.S. increase STEM skills and opportunities for all Americans?*

In this report, the NSB highlights four elements of S&E leadership that are essential to the U.S. remaining the world leader in innovation in 2030: Practice of Science and Engineering, Talent, Partnerships, and Infrastructure. We conclude by offering a Roadmap for actions the NSB and the National Science Foundation (NSF) will undertake to help address the key questions posed above.[7] The NSB commits to working with all stakeholders in our S&E enterprise – including Congress, the Administration, federal agencies, state and local governments, academia, and the private sector – to bring about the next era of American innovation leadership.

FUNDAMENTAL RESEARCH According to National Security Decision Directive (NSDD)-189, fundamental research includes basic and applied research in science and engineering, which the Organization for Economic Cooperation and Development (OECD) Frascati Manual defines as follows:[8]

BASIC RESEARCH Experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view.

APPLIED RESEARCH Original investigation undertaken in order to acquire new knowledge, directed primarily towards a specific, practical aim or objective.

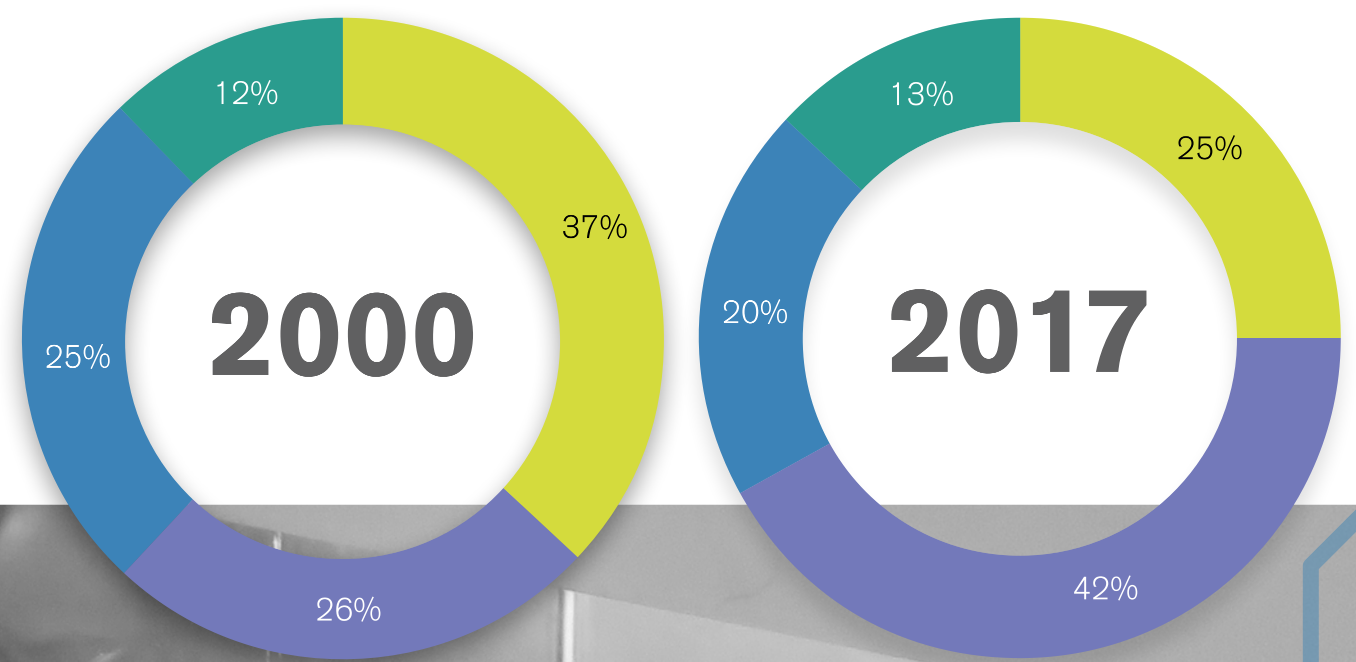
EXPERIMENTAL DEVELOPMENT Systematic work, drawing on knowledge gained from research and practical experience and producing additional knowledge, which is directed to producing new products or processes or to improving existing products or processes.

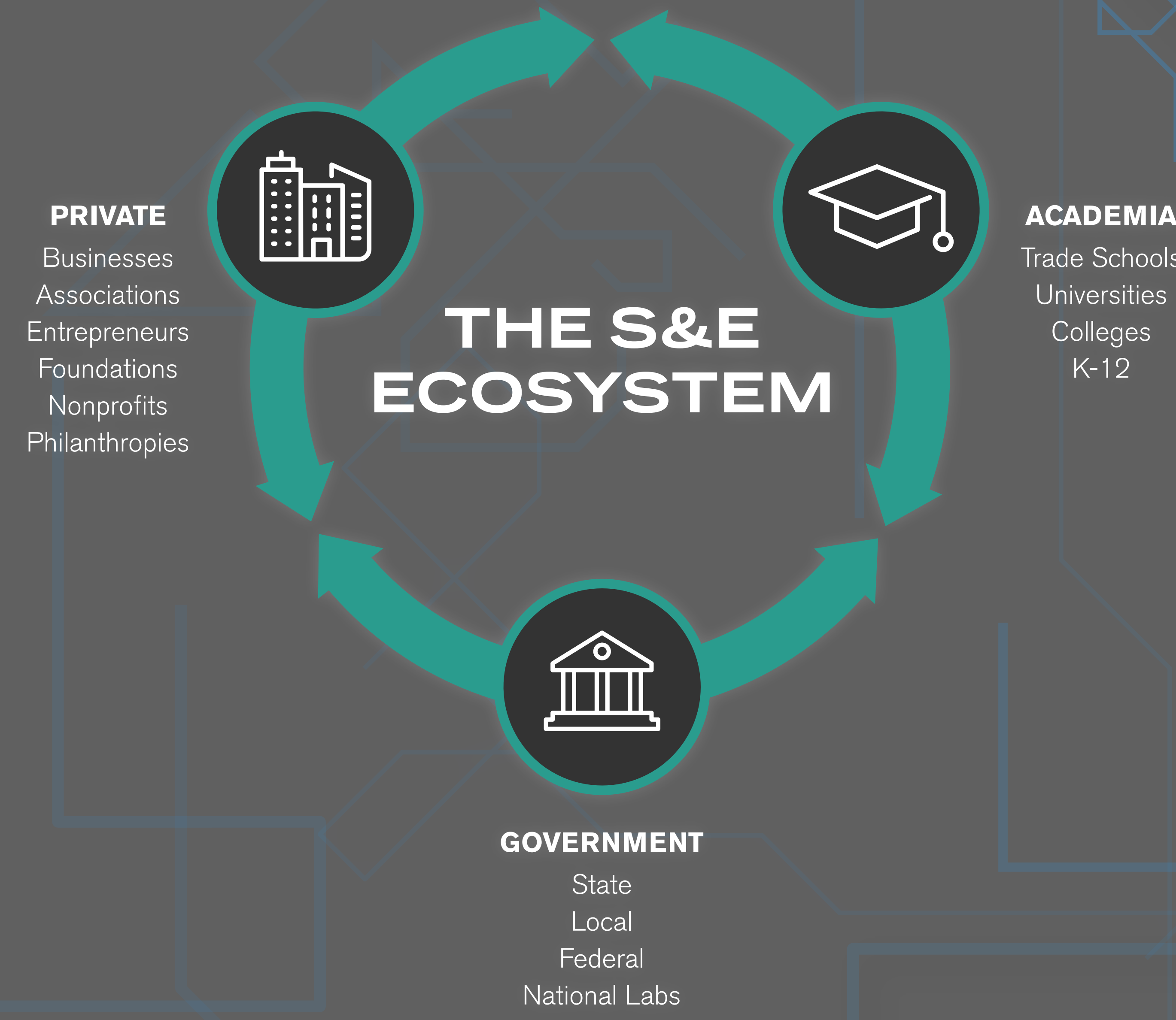
FIGURE 1: AMERICA'S SHARE OF R&D DECREASING AS GLOBAL S&E GROWS

While the U.S. investment in R&D continues to grow in absolute terms, the investment by other countries is growing faster. As a result, the U.S. share of global R&D spending decreased from 37% to 25% between 2000 and 2017.

Source: NSB, "Research and Development: U.S. Trends and International Comparisons," *Science & Engineering Indicators 2020*

- United States
- East-Southeast and South Asia
- European Union
- Rest of World





ELEMENTS OF LEADERSHIP

ELEMENT: PRACTICE OF SCIENCE AND ENGINEERING

For the U.S. to preserve its lead in fundamental research and empower its businesses and enterprises to compete globally, it must stay on the leading edge of the practice of S&E. This entails being more strategic about investments, making the S&E ecosystem more nimble, embracing new research tools and modalities, fostering an inclusive and ethical S&E enterprise, welcoming and capitalizing on the globalization of S&E, and retaining the American public's trust.

The nation must make both near and long-term research investments in fields such as Artificial Intelligence (AI) and Quantum Information Systems that are key to U.S. competitiveness, while continuing to invest in a broad array of fundamental research. This two-pronged approach is needed to remain globally competitive in fields "of the moment" and to create the research environment and basic knowledge that will yield the next revolutionary advancement. While industry is well positioned to advance knowledge in targeted fields, only the federal government can invest across all fields, across the nation, at scale, and over sufficiently long-time horizons to create new knowledge that will help us to address future security, health, and economic challenges.

At the same time that the U.S. invests in promising research, it must do more to ensure that discoveries are translated into innovations. While the U.S.'s decentralized, bottom-up approach to S&E research produces new knowledge in many disciplines, it can result in that knowledge being siloed and less likely to make the leap from the research environment to industry. Policies, incentives, and processes that improve collaboration across disciplines, between government S&E agencies, and among government, academia, and industry, can facilitate that translation. Additionally, with the private sector playing a larger role in supporting some fields of fundamental research, S&E leaders must think about mutually beneficial ways to ensure that information flows among government, universities, and industry travel in all directions.

To stay at the forefront of the practice of S&E, the U.S. must be at the leading edge of research modalities and tools that are likely to change the practice of research or to shift paradigms. Over the next decade, the U.S. will have to adapt to technological advances by creating structures and implementing coordination strategies that take full advantage of the opportunities they present. For example, AI may alter how research questions are asked and answered, enable diverse fields to collaborate in new ways, and require broader input and social science collaborations as the U.S. develops new norms, practices, and standards. Approaches such as convergent research, which bring together diverse disciplines to explore problems that cross the boundaries of multiple fields, have the potential to influence how disciplines are organized and how funding agencies invest. The funding choices that agencies make will be critical to motivating funding recipients to move in new directions and evaluate and modify their respective organizations and strategic priorities.

In the coming decade, the U.S. also must continue to improve the research environment, setting the standard for research ethics and values. To do so, the U.S. must embrace and champion core values of objectivity, honesty, openness, fairness, accountability, and stewardship. Furthermore, as the U.S. looks to the future, attention to falsification, plagiarism, and fabrication per se will not suffice to ensure research integrity.[9] Researchers at U.S. institutions must also disclose fully all conflicts of commitment or interest that can prejudice incentives or motivations. As part of setting the standard on values, the research enterprise must do more to create a welcoming and inclusive culture of S&E. Hostile research environments in U.S. labs, classrooms, and workplaces must not be tolerated. A sustained focus on scientific values and the culture of the S&E enterprise will be critical as the U.S. seeks to model open, ethically conducted science and engineering and sustain a global community of like-minded partners.

In a world where transnational collaboration in S&E is becoming more critical, the U.S. must support researchers' collaborations with scientists abroad. These collaborations and the progress of knowledge itself depend on preserving the open flow of knowledge. At the same time, it will be crucial that the U.S. safeguard sensitive areas of research in which national security considerations must prevail. The nation's guide in doing so should be President Ronald Reagan's policy on technology transfer (NSDD-189), which called for the products of fundamental research to remain unrestricted to the maximum extent possible.[12]

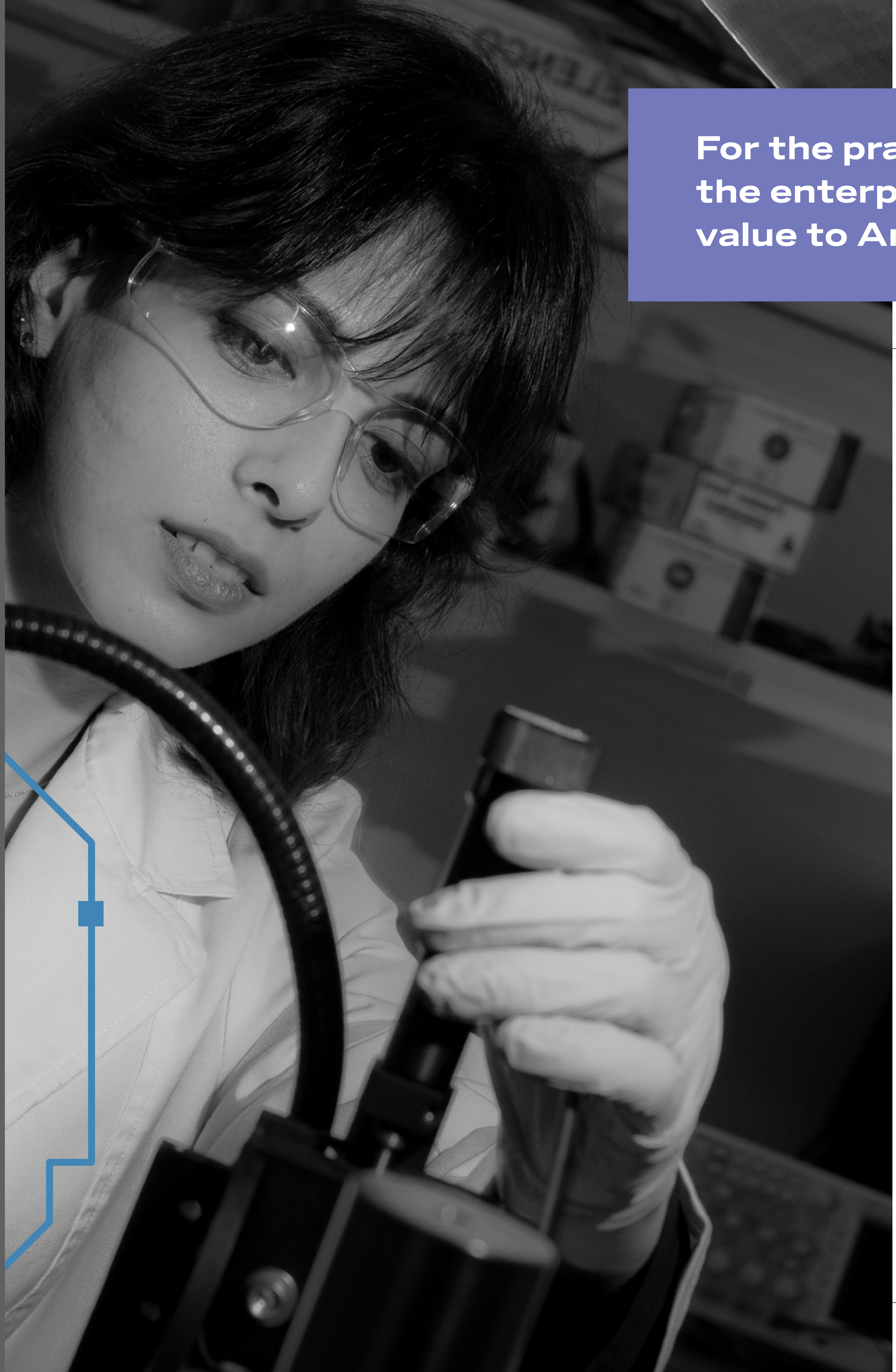
For the practice of S&E to flourish, the enterprise must also show its value to Americans. In part, that means demonstrating how S&E can help address real world challenges. Support for use- and problem-inspired research – as exemplified by NSF's Convergence Accelerators[13] initiative – is a tangible step in this direction.

The U.S. must remain globally competitive in fields "of the moment" and create the research environment and basic knowledge that will yield the next revolutionary advancement.

NSF ACTIONS ON SCIENCE & SECURITY

To balance an open, global environment of fundamental research with national and economic security, the NSF has taken steps to address science and security concerns. Specifically, the agency has:[11]

- **Clarified its conflicts of interest disclosure requirements** to ensure proposers provide information on all sources of current and pending research support.
- **Clarified the biographical sketch disclosure requirements and standardized the format of the biographical sketch** to ensure that any titled position is identified, whether or not remuneration is received.
- **Required that all NSF personnel and those at NSF under an Intergovernmental Personnel Act Agreement (IPA) are U.S. citizens.**
- **Prohibited all NSF personnel and IPAs from participating in a foreign talent recruitment program.**
- **Developed training for NSF employees on science and security.**
- **Participated in coordinating policy and practices on science and security** with the White House, with sister science agencies, and with the intelligence and law enforcement communities.
- **Created the position of Chief of Research Security Strategy in the Office of the Director to provide NSF leadership with policy advice** on all aspects of research security and strategy and coordinate with other federal agencies and the White House.



For the practice of S&E to flourish, the enterprise must also show its value to Americans.

NEW NSF TERM AND CONDITION ON HARASSMENT AND SEXUAL ASSAULT

NSF's October 2018 term and condition on harassment and sexual assault reaffirms the agency's commitment to fostering safe and sustainable research and educational environments for all in the U.S. S&E ecosystem.[10] Excerpts include:

> "The Principal Investigator (PI) and any co-PI(s) identified on an NSF award are in a position of trust. These individuals must comport themselves in a responsible and accountable manner during the award period of performance, whether at the awardee institution, on-line, or at locales such as field sites, facilities, or conferences/workshops."

> "Other personnel supported by an NSF award must likewise remain in full compliance with awardee policies or codes of conduct, statutes, regulations, or executive orders relating to sexual harassment, other forms of harassment, or sexual assault."

ELEMENT: TALENT

Talent is the treasure on which America's S&E enterprise and the nation's prosperity, health, and security depend. Today, S&E knowledge and skills matter not only for scientists and engineers engaged in R&D, but also for a range of jobs across the economy that historically did not require such skills. To respond to these changes, the U.S. will need a workforce to push the frontiers of knowledge and that has the skills to thrive in a knowledge- and technology-intensive economy.[14] To lead in S&E and remain globally competitive in 2030, the U.S. must be a STEM talent powerhouse that uses a two-pronged strategy of expanding domestic talent while continuing to attract and retain global talent.

Increasing the STEM skills and opportunities for all Americans will require local, state, and federal governments, public and private educational institutions, community organizations, and industry to step up their efforts. The U.S. needs "all hands on deck" to modernize its education system, reinvest in public elementary, secondary, and post-secondary education,[15] and support the reskilling/upskilling that workers will need throughout their careers.

Despite the emphasis on K-12 STEM education in recent years, American students' test scores have stagnated over the past decade. The science and mathematics performance of U.S. students consistently ranks below that of students in many competing nations. Results from the 2018 OECD's Programme for International Student Assessment (PISA) placed U.S. fourth and eighth graders 18th in science and 37th in mathematics out of 79 participating countries or economic regions.[16]

Improving K-12 student performance in STEM will require mechanisms to bring the best research-based STEM pedagogy and practices to the classroom in every school in the country. NSF-funded research has shown successful training and teaching approaches and these and other proven practices should be broadly implemented in America's schools. Teacher education programs must incorporate more STEM education so that primary school teachers have the skills and comfort level they need to nurture young children's natural curiosity, avoiding "lost Einsteins."[17]

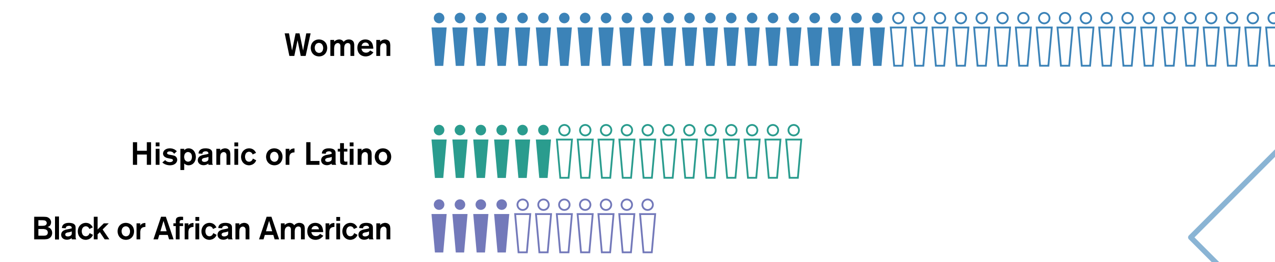
> **Our message must be clear: Just as illiteracy is unacceptable, it can no longer be acceptable for anyone to be "bad at math."**

At the post-secondary level, the U.S. must embrace a pathways model[18] to workforce development. Because entry into the STEM workforce is not always via a linear high school – university – workforce path, the U.S. must offer individuals, from skilled technical workers[19] to PhDs, on-ramps into STEM-capable jobs. The U.S. must also deepen partnerships between educational institutions and the business sector to prepare Americans for the industries of the future and support reskilling and upskilling of incumbent workers so that they can better navigate rapid changes in the world of work.

In order to lead in 2030, the U.S. also must be aggressive about cultivating the fullness of the nation's domestic talent. Although the proportion of Black and Hispanic representation in S&E jobs rose slightly from 1995 to 2017, these groups remain underrepresented compared to their proportion in the general population.[20] Over the past two decades, the number of women in S&E occupations has doubled. Yet despite comprising over half of the college-educated workforce, as of 2017, women account for just 29% of the S&E

FIGURE 2: MISSING MILLIONS: FASTER PROGRESS IN INCREASING DIVERSITY NEEDED TO REDUCE SIGNIFICANT TALENT GAP

While the number of people from under-represented groups in the S&E workforce has grown over the past decade, much faster increases will be needed for the S&E workforce to be representative of the U.S. population in 2030. To achieve that goal, the NSB estimates that the number of women must nearly double, Black or African Americans must more than double, and Hispanic or Latinos must triple the number that are in the 2020 U.S. S&E workforce. These estimates are based on projections from the U.S. Census and Bureau of Labor Statistics, together with data from the National Center for Science and Engineering Statistics, and assume that participation of these groups in the S&E workforce increases at current rates.



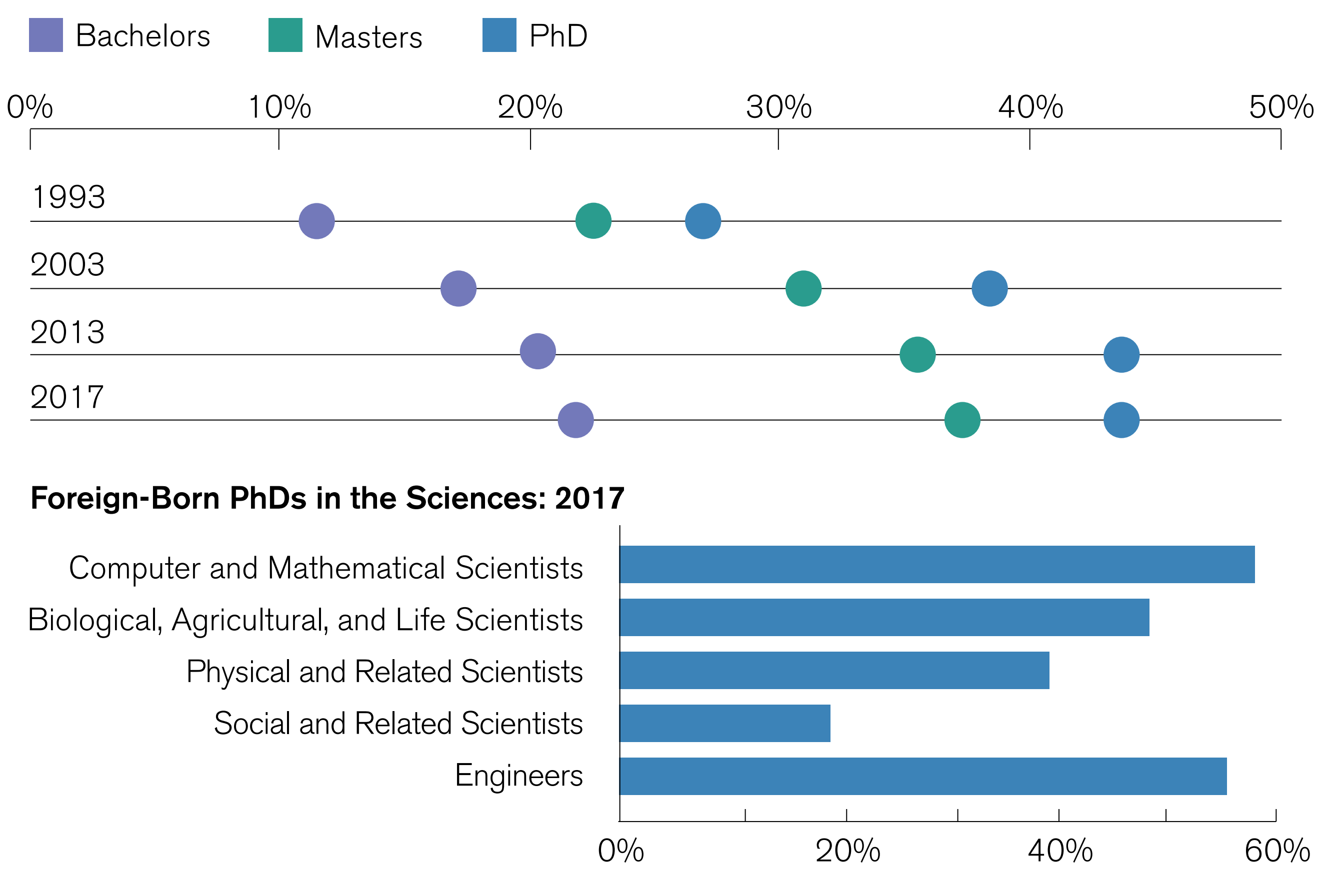
Legend

x 100,000 people in 2020 S&E workforce

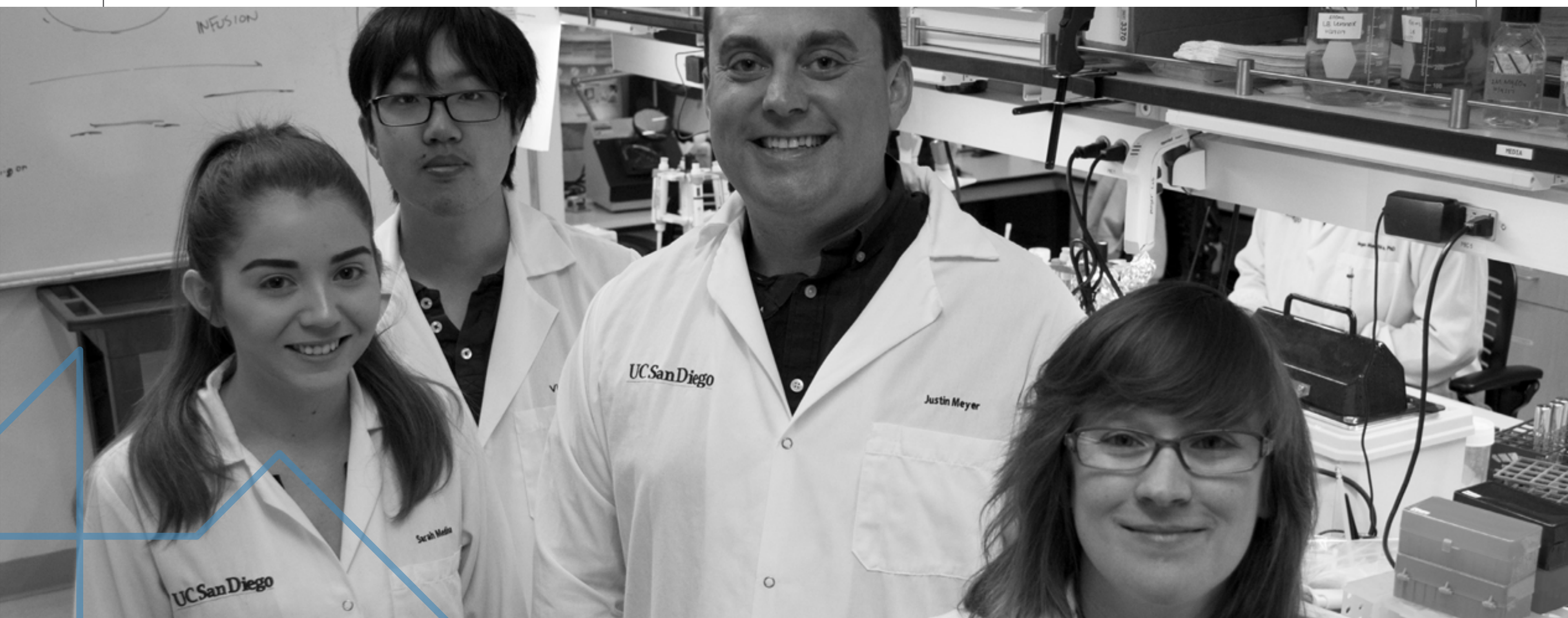
x 100,000 additional people needed in 2030 for the S&E workforce to representative of the U.S. population

FIGURE 3: FOREIGN-BORN INDIVIDUALS ARE SIGNIFICANT CONTRIBUTORS TO U.S. S&E

The share of foreign-born S&E workers has increased significantly in the last 25 years. In most S&E occupations, the higher the degree level, the greater the proportion of the workforce that is foreign-born. The percentages are highest in the fields of engineering and computer science — almost 6 out of 10.



Source: NSB, "Science and Engineering Labor Force," *Science & Engineering Indicators 2020*



DIVERSITY A collection of attributes that includes national origin, language, race, color, disability, ethnicity, gender, age, religion, sexual orientation, gender identity, socioeconomic status, veteran status, and family structures. It encompasses differences among people concerning where they have lived and their respective life experiences.

INCLUSION A culture that connects each employee, encourages collaboration, flexibility, and fairness, and leverages diversity so that each person may participate and contribute to their full potential.

(Adapted from Office of Personnel Management, Office of Diversity and Inclusion)

workforce and are especially underrepresented in fields identified as critical to future industries such as engineering and computer science.[21] These data show that progress in creating a diverse and inclusive S&E enterprise has not kept pace with demographic trends or with the increasing centrality of S&E to our economy, national security, and jobs of the future (see Figure 2). America's diversity is a great strength.[22] Leveraging that strength by broadening participation in the U.S. S&E enterprise will be crucial to fostering individual opportunity and a thriving economy.

To develop a talent pool that is second to none, the U.S. must also continue to attract and retain talent from around the globe. Even as we develop domestic talent, the U.S. economy will continue to need foreign S&E talent. Foreign-born individuals represent a substantial share of our S&E workforce and data show that the share of foreign-born S&E workers has increased significantly over the last 25 years. For example, in computer science, mathematics, and engineering — fields that underpin many of the Industries of the Future[23] — nearly 60% of Ph.D. holders in the U.S. workforce are foreign-born (see Figure 3).[24]

As the stature of universities and S&E ecosystems in emerging economies grow — and with it a global bidding war for S&E talent — it is far from a foregone conclusion that foreign students and workers will continue to choose the U.S. as a place to study and work. Declines in stay rates[25] for individuals from China and India — the two largest sources of international S&E talent — coupled with declines in foreign student enrollment in U.S. higher education institutions already suggest growing opportunity elsewhere.[26] The lagging nature of stay rate data suggests that there may be even more significant changes in talent migration patterns that are not yet reflected in current statistics.

To attract the very best talent from across the globe, the U.S. must welcome international students and workers from all continents. Ensuring that international students and workers have attractive opportunities and feel secure in their choice to come to the U.S. begins with a clear, consistent, and predictable visa system. Such a system would assure students of stability in their studies **as well as** remain in and contribute to the country after completing their degrees.

For the U.S. to remain a STEM talent powerhouse, it cannot make a choice between developing domestic talent or recruiting foreign-born talent. The U.S. must ensure that it is a magnet for **all** STEM talent — domestic and foreign.

ELEMENT: INFRASTRUCTURE

For the U.S. to remain a global leader in innovation, America's researchers must have access to scientific facilities that will astonish the world – tools that let them see further, faster, and deeper. This infrastructure is critical for fundamental research, empowering U.S. businesses and entrepreneurs, and developing and attracting STEM talent. The world's best talent – including American talent – will go where S&E opportunities are greatest. Increasingly, infrastructure is an essential part of that equation. Research infrastructure also symbolizes a nation's commitment to S&E, since it represents a significant, long-term undertaking.

As we look to 2030, the NSB sees three infrastructure imperatives:

- The U.S. must invest in infrastructure, including data, software, computation, and networking capabilities, across all S&E disciplines.
- To catalyze regional scientific and innovation networks, America must strategically build S&E infrastructure and capacity in the nation's underserved areas and institutions, while retaining excellence and capacity where it already exists.[27]
- For the most complex and costly facilities, for which only one or two of a kind are needed worldwide, the U.S. must cooperate with other countries, such that U.S. researchers can participate fully, help set the agenda, and share equitably in the results.

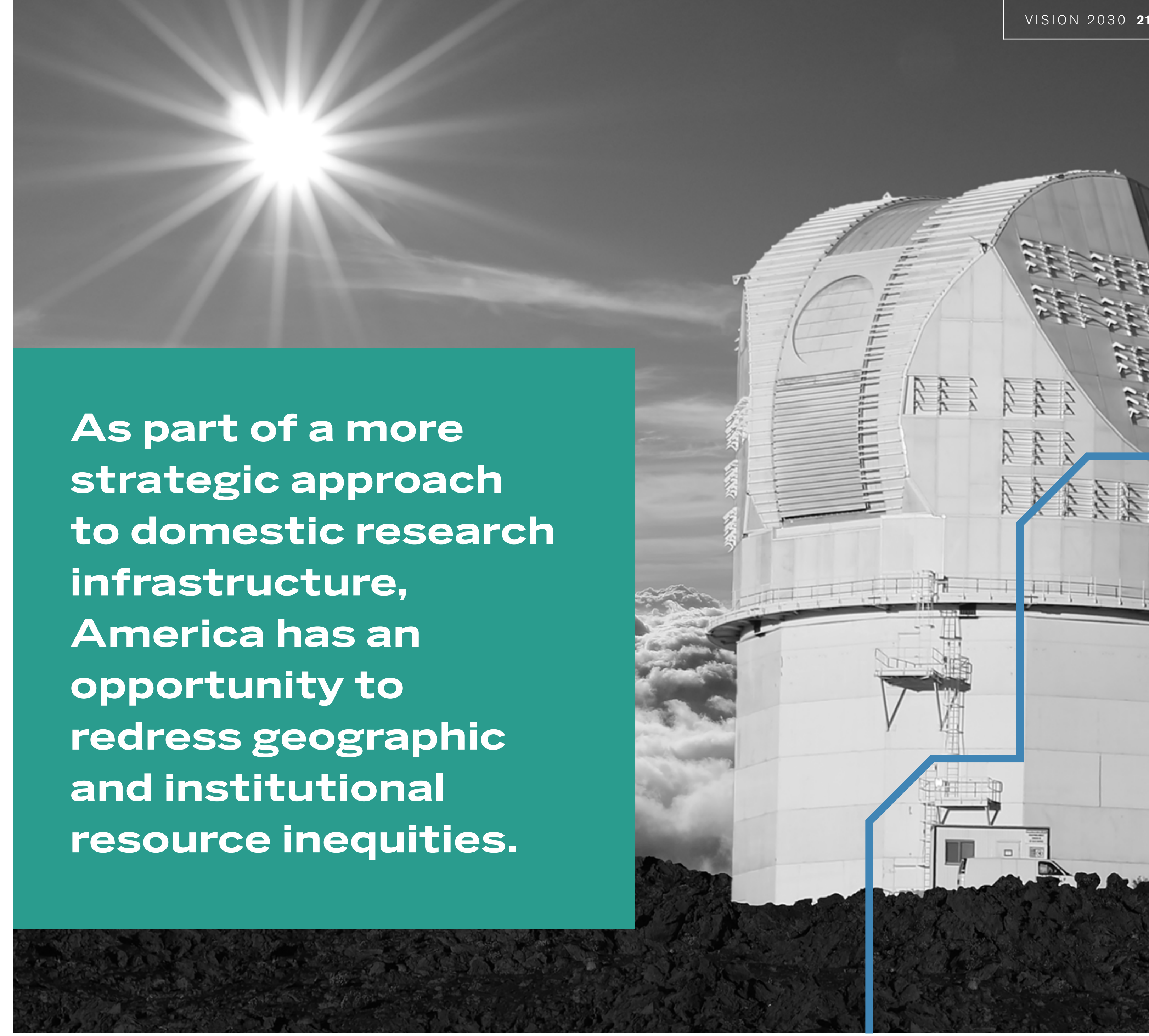
Research infrastructure needs for 2030 and beyond will range from desktop microscopes, to billion-dollar telescopes, to deep ocean submersibles, to the research cyberinfrastructure resources that underpin revolutions in big data and AI. Providing research infrastructure across the range of scientific fields and at various scales will require field-based, agency-based, and interagency planning and execution to ensure that infrastructure investments are complementary and that America's S&E infrastructure is globally competitive.

As the NSB stated in its 2018 report on midscale research infrastructure, current gaps in agency support of mid-scale research infrastructure put future areas of U.S. S&E research at risk.[28] Investing in capabilities that are more modest in scope can expand the types of research that can be accomplished and lay the groundwork for building the next generation of large or mega-facilities.

Predictable budgets, strategic planning, and sustained agency and interagency partnerships for America's large facilities will be especially crucial because of their costs and multi-decade lifecycle.

As part of a more strategic approach to domestic research infrastructure, America has an opportunity to redress geographic and institutional resource inequities. More regional, integrated suites of midscale research infrastructure – including cyberinfrastructure – would catalyze research across a range of institutional types, diversify the S&E enterprise, and lay the groundwork for greater geographic distribution of S&E-based industries.

The cost of building new facilities is growing most rapidly in fields where scientists and engineers need bigger instruments to see smaller things or where continental-scale networks offer the keys to new knowledge. Over the next decade, the federal government will need to make funding decisions on a few large-scale S&E infrastructure projects. The cost or geographic extent of these facilities may exceed what America can commit to alone. In such cases, the U.S. should prioritize investments – for example, facilities with high potential to impact S&E, economic vitality, or national security – and determine participation in international partnerships by carefully considering the global S&E landscape and opportunities for American leadership.



As part of a more strategic approach to domestic research infrastructure, America has an opportunity to redress geographic and institutional resource inequities.

ELEMENT: PARTNERSHIPS

The U.S. must update its approach to S&E partnerships so that American discoveries empower U.S. businesses and entrepreneurs to compete globally.

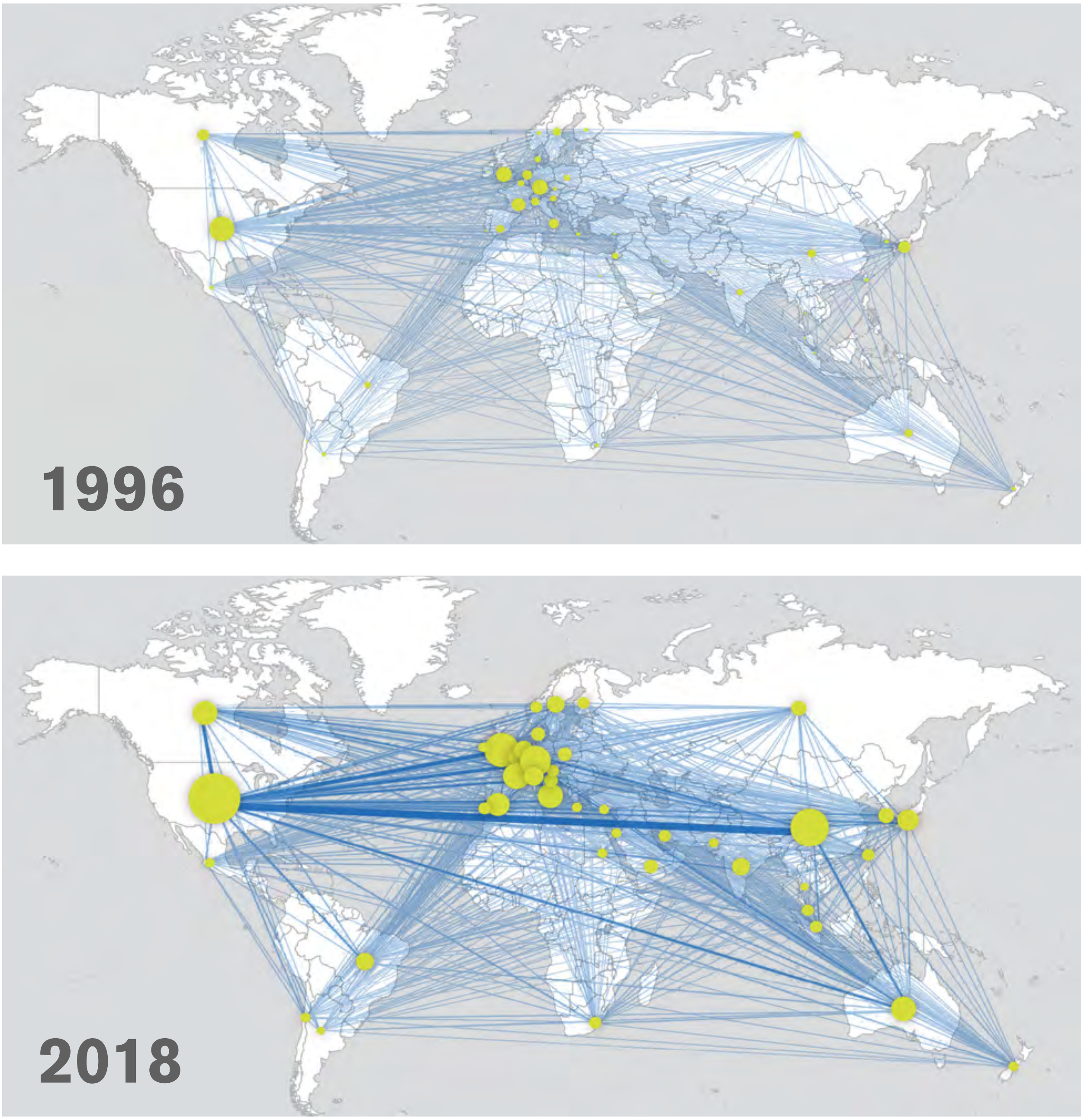
America's largely decentralized S&E ecosystem of education, workforce development, and S&E R&D is knitted together via partnerships. For seven decades the federal government has partnered with academia to conduct basic and applied research. More recently, partnerships between academia and industry have further catalyzed the translation of research into innovation. Partnerships among all levels of government, public and private educational institutions, and industry have played a role in education and training. Bottom-up, community-driven solutions bring creativity, innovative approaches, dynamism, and flexibility to the S&E ecosystem.

As the U.S. faces increased competition from countries that organize their S&E enterprises much more centrally, it must ensure that its ecosystem amounts to more than the sum of its parts by strengthening existing partnerships and adding more partnerships with state governments and philanthropic organizations.

To increase the impact of investment and deliver more returns to Americans, a renewed government-university-industry partnership will require:

- Sustained federal government support of fundamental research – the "seed corn" of the S&E enterprise.
- Improved translation of basic research through mechanisms at NSF and partnerships with mission agencies, national labs, or industry.
- Mitigating procedural or cultural obstacles to collaboration among government science agencies, including the Department of Defense, and between universities, national laboratories, and industry.
- Streamlining federal regulations to enhance technology transfer by creating greater flexibility for public-private partnerships, more engagement with private-sector investors, and improved support for innovation.

FIGURE 4: INTERNATIONAL COLLABORATION AMONG RESEARCHERS GROWS DRAMATICALLY



Collaboration among scientists and engineers around the world enhances research capacity. In 1996, U.S. researchers most frequently co-authored papers with researchers in Europe and Japan. In 2018, these connections have grown – as shown by the width of the lines, with the size of the circles denoting the relative number of publications. Now, China has emerged as the single most frequent partner with the U.S. in research collaboration.

Source: NSB, "Publications Output: U.S. Trends and International Comparisons," *Science & Engineering Indicators 2020*

Building strong, enduring government, academic, and industry partnerships starts with clearly defining the benefits to all parties and clarifying issues such as intellectual property rights. Effective partnerships also require flexibility when dealing with another organization's procedural or cultural norms, particularly when the parties have different overarching missions or motivations.

As the U.S. builds partnership capacity at home to respond to a more competitive global S&E landscape, the nation simultaneously needs to enhance capacity for its researchers to collaborate with their global counterparts. Over the past decade, international research partnerships have made possible some of the era's most exciting scientific breakthroughs including the discovery of the Higgs Boson, the detection of gravitational waves and high-energy cosmic neutrinos, and the first image of a black hole.

International research partnerships are already a key feature of the globalized era of S&E. Among the top 15 countries publishing scientific articles, 41% of all articles include international collaboration.[29] And the share of all global articles published with international collaboration is on the rise (see Figure 4); between 2008 and 2018, the percentage of global articles published with international collaboration increased from 17% to 23%.[30] In 2018, about a quarter of internationally coauthored publications with an author at an American research institution have a coauthor with a Chinese professional affiliation.[31]

The U.S. must make it a priority to be a prominent, strong, and reliable partner in international scientific collaborations. These collaborations are vital because they foster science and engineering on a global scale, train the next generation of R&D workers, bring cultural, economic, and political benefits, and allow the U.S. to leverage its resources in the operation of large-scale research facilities that are too costly for any single nation to manage on its own. Strong U.S. presence also provides a means by which the U.S. can strengthen global acceptance of the core values of open, transparent, and ethical conduct of S&E research.

The U.S. must build partnership capacity at home to respond to a more competitive global S&E landscape and enhance capacity for its researchers to collaborate internationally.

FOCUS ON THE FUTURE: NSB ROADMAP

DELIVER BENEFITS FROM RESEARCH

DEVELOP STEM TALENT FOR AMERICA

EXPAND THE GEOGRAPHY OF INNOVATION

FOSTER A GLOBAL S&E COMMUNITY

NSB ROADMAP

To remain the world leader in basic research and innovation, the U.S. must embrace its identity as the land of opportunity, utilize the can-do attitude that defines its people, and race to lead a future in which ideas are forged on a global scale. The nation's S&E ecosystem must respond with a partnership that embodies the strength of its values – a spirit of exploration, of wonder, of discovery, coupled with a willingness to take risks and an emphasis on freedom and individual creativity.

For its part, the NSB will continue to collect and communicate data on the U.S. and global S&E landscape, convene and collaborate across the national S&E ecosystem, and advocate for fundamental research and policies that will help the U.S. remain a global leader. The NSB will focus our efforts in these main areas: delivering benefits from NSF investments in creating new knowledge, developing STEM talent for America, expanding the geography of innovation within the U.S., and fostering a global S&E community. **This Roadmap charts the actions to which NSB commits in partnership with NSF and other leaders in the S&E enterprise.**

KEY QUESTIONS

- How can America keep its lead in fundamental research?
- How can American discoveries continue to empower U.S. businesses and entrepreneurs to succeed globally?
- How can the U.S. increase STEM skills and opportunities for all Americans?

DELIVER BENEFITS FROM RESEARCH

NSB has endorsed the principle that "all [NSF]-funded research and education must further the national interest by contributing to the [NSF's] mission."

While several agencies invest in fundamental research, NSF is the only agency whose sole mission is to do so across a wide breadth of disciplines. Its practice of supporting curiosity-driven research has provided the basis for technologies and benefits that could not have been anticipated at the time of initial funding. To enhance the return to U.S. taxpayers from these investments and empower the nation's businesses and entrepreneurs to compete globally, the U.S. must build on progress from the past decade, improve coordination, and speed translation from discovery to innovation.

PROGRESS

In the last decade NSF has taken significant steps to ensure that the U.S. and its taxpayers benefit from the research it supports, including through policies on research in the national interest, accountability and transparency, and the broader impacts criterion in its Merit Review process. The agency has also created new programs (e.g., INCLUDES, I-Corps, National Artificial Intelligence Research Institutes, and Convergence Accelerators) targeting national priorities and societal challenges.

NSB Actions:

- Evaluate how NSF's broader impacts merit review criterion could better meet societal needs.
- In partnership with NSF leadership, undertake an organizational review and offer recommendations on changes to directorate structure, funding models, or programmatic offerings, including for convergent research and questions inspired by societal problems.
- To advance discovery and innovation, ensure NSF continues, completes, and implements an agency-wide partnerships strategy that includes industry and federal mission agencies.

To leverage America's lead in basic research, the country must find ways to speed the path from discovery to innovation.

COORDINATION

NSB Actions with NSF to improve strategic planning across the U.S. S&E ecosystem:

- Use initiatives like the "Big Ideas" to focus awareness and funding of national priorities and emerging opportunities.
- Ensure NSF's budgetary strategy fosters discovery, complements investments in fundamental research made by industry and other federal agencies, and reflects national research needs, including critical technologies.
- Identify and make strategic recommendations on emerging areas of S&E research where the U.S. must be preeminent and government actions are required, including by leveraging *Science & Engineering Indicators* and NSF's deep connections to America's colleges and universities.

TRANSLATION

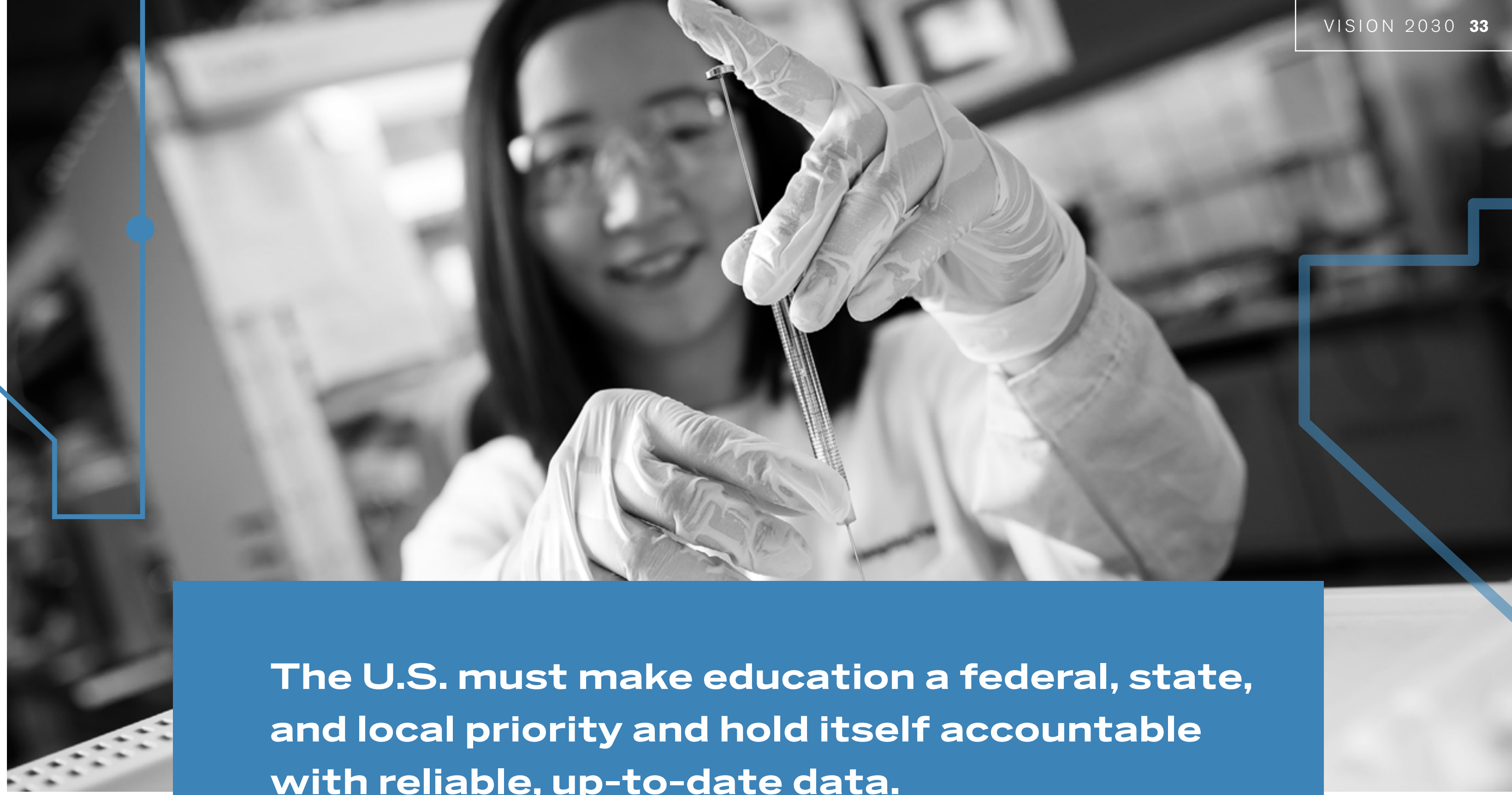
To leverage America's lead in basic research, the country must find ways to speed the path from discovery to innovation, through partnerships among governments, universities, and the private sector.

NSB Actions:

- Encourage the exchange of people, and with that the exchange of ideas and expertise, among federal agencies, universities, and industry, including through programs like the Industry – University Cooperative Research Centers and Convergence Accelerators.
- Convene university, industry, and state partners to identify best practices and barriers (regulatory, structural, administrative) to partnerships and translation of NSF-funded basic research.
- As part of a review of NSF, develop options for structures and processes that would magnify translation of discoveries, including consideration of a new NSF directorate focused on translation.

DEVELOP STEM TALENT FOR AMERICA

To keep its lead in fundamental research and bolster the workforce of the future, the U.S. must provide opportunities for all Americans and continue to welcome foreign talent.



The U.S. must make education a federal, state, and local priority and hold itself accountable with reliable, up-to-date data.

DOMESTIC TALENT: A LAND OF OPPORTUNITY

America's future STEM-capable workforce must engage all Americans, lead its competitors in preparation and competence, and enjoy sustainable and attractive STEM careers. The U.S. must make education a federal, state, and local priority and hold itself accountable with reliable, up-to-date data. Post-secondary education, from skilled technical programs to PhDs, must be made more affordable and accessible.

NSB Actions:

- Support NSF strategies to further the broad adoption and use of NSF-funded STEM education research, including research on teaching critical thinking, problem-solving, creativity and digital literacy, and on STEM pedagogy and practices for diversity and inclusion.
- Advocate for more science and engineering teaching in K-12 education, with an emphasis on increasing contact hours and exposure to science in early education and improving the quality of STEM education at all levels.

NSB Actions with NSF:

- Advocate for new investment to NSF talent programs, including Advanced Technological Education, Research Experiences for Undergraduates, graduate research fellowships, and post-doctoral fellowships.
- Ensure that NSF improves the attractiveness, equity, and inclusivity of research careers, including attracting and retaining women and other underrepresented groups; and ensuring that these groups are achieving leadership roles in the S&E ecosystem through appropriate policies, funding, programs, and outreach.
- Develop recommendations aimed at increasing the attractiveness of conducting academic research in the U.S. and the retention and productivity of researchers. This may include:
  - » Examining increased investment to fund a higher percentage of highly rated proposals
  - » Changes to grant structures to reduce administrative burden
  - » Mechanisms to fund long-term non-tenure researchers
  - » Creating and/or adapting funding opportunities to stay competitive with the opportunities available to researchers elsewhere in the world
- Continuing to engage with NSF's National Center for Science and Engineering Statistics (NCSES) to collect, analyze, and communicate data on the STEM-capable workforce, including the new emphasis on the skilled technical workforce.[30]

INTERNATIONAL TALENT: A BEACON FOR THE WORLD

NSB Actions:

- Encourage Congress and the Administration to ensure that the U.S. is welcoming to the best science and engineering talent from around the globe. This includes having clear and consistent visa policies and sustaining efforts to retain U.S.-educated scientists and engineers.
- Work with NCSES to improve data on talent migration, including U.S.-born citizens, into and out of the U.S.

EXPAND THE GEOGRAPHY OF INNOVATION

Americans from every state must benefit from the progress of science and engineering and have access to high-quality STEM education and S&E careers.

Empowering American workers, entrepreneurs, and businesses will require strategically building S&E capacity and infrastructure across the nation and actively seeding and nurturing innovation clusters.

NSB Actions:

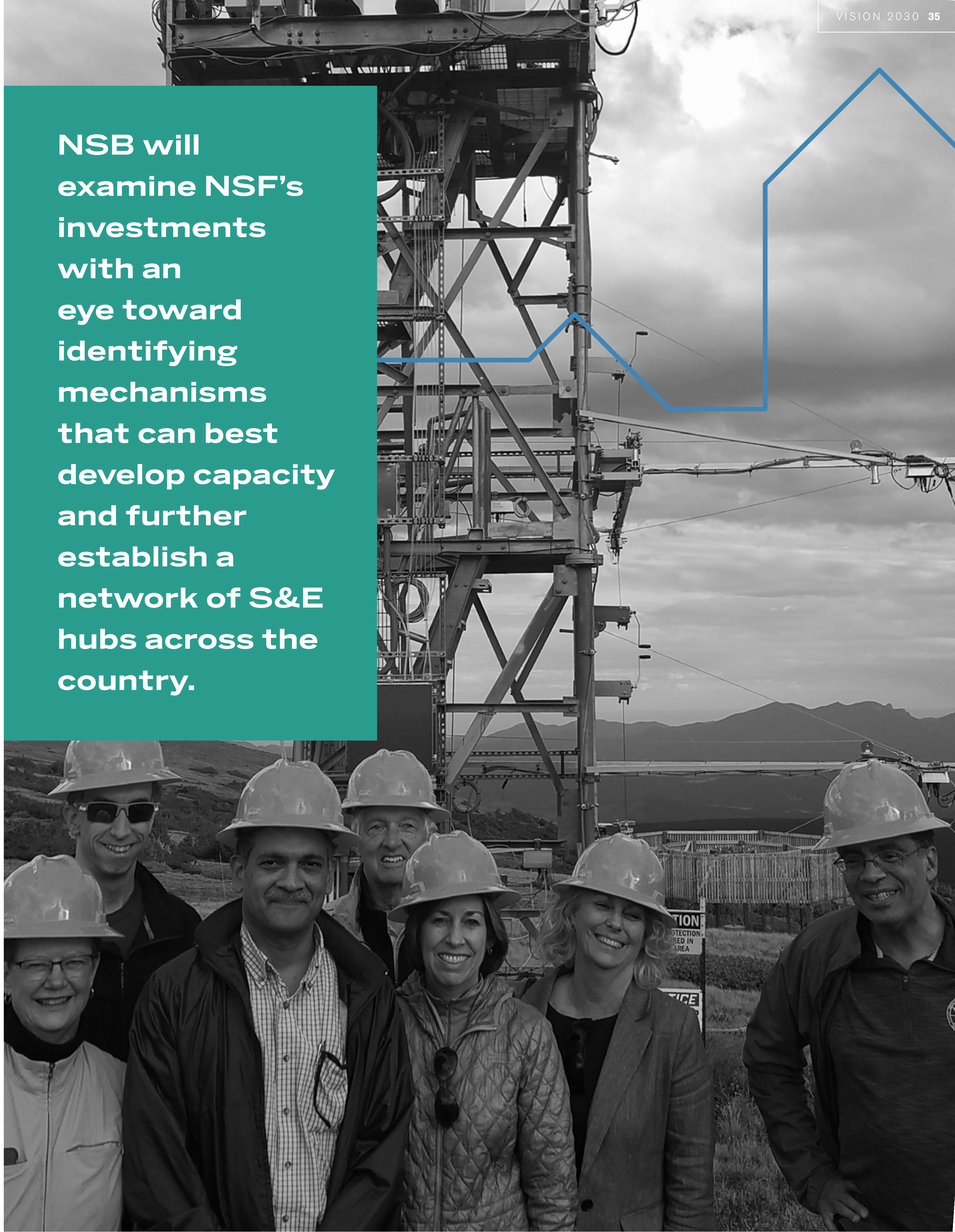
- Conduct a review of NSF strategies to expand S&E capacity in all states. In this effort, NSB will obtain input from state and industry stakeholders and examine NSF's investments in research, research infrastructure, and education with an eye toward identifying mechanisms that can best develop capacity and further establish a network of S&E hubs across the country.
- Advocate for including communities potentially impacted by NSF-funded grants in research design considerations and encourage public participation in research, including through "citizen science."

Public research universities provide key public goods, but face distinct challenges as they strive to provide affordable, quality education to a broad range of students, perform two-thirds of academic R&D,[32] and contribute to local economies.

NSB Actions:

- Communicate to Congress and the Administration the benefits of a new federal program for public post-secondary education institutions that would prepare STEM-capable Americans in every state and encourage partnerships between state and local governments, educational institutions, and industries.
- Continue to advocate for state-level reinvestment in public higher education, using *Science & Engineering Indicators* data to document the impact of disinvestment.

NSB will examine NSF's investments with an eye toward identifying mechanisms that can best develop capacity and further establish a network of S&E hubs across the country.



FOSTER A GLOBAL S&E COMMUNITY

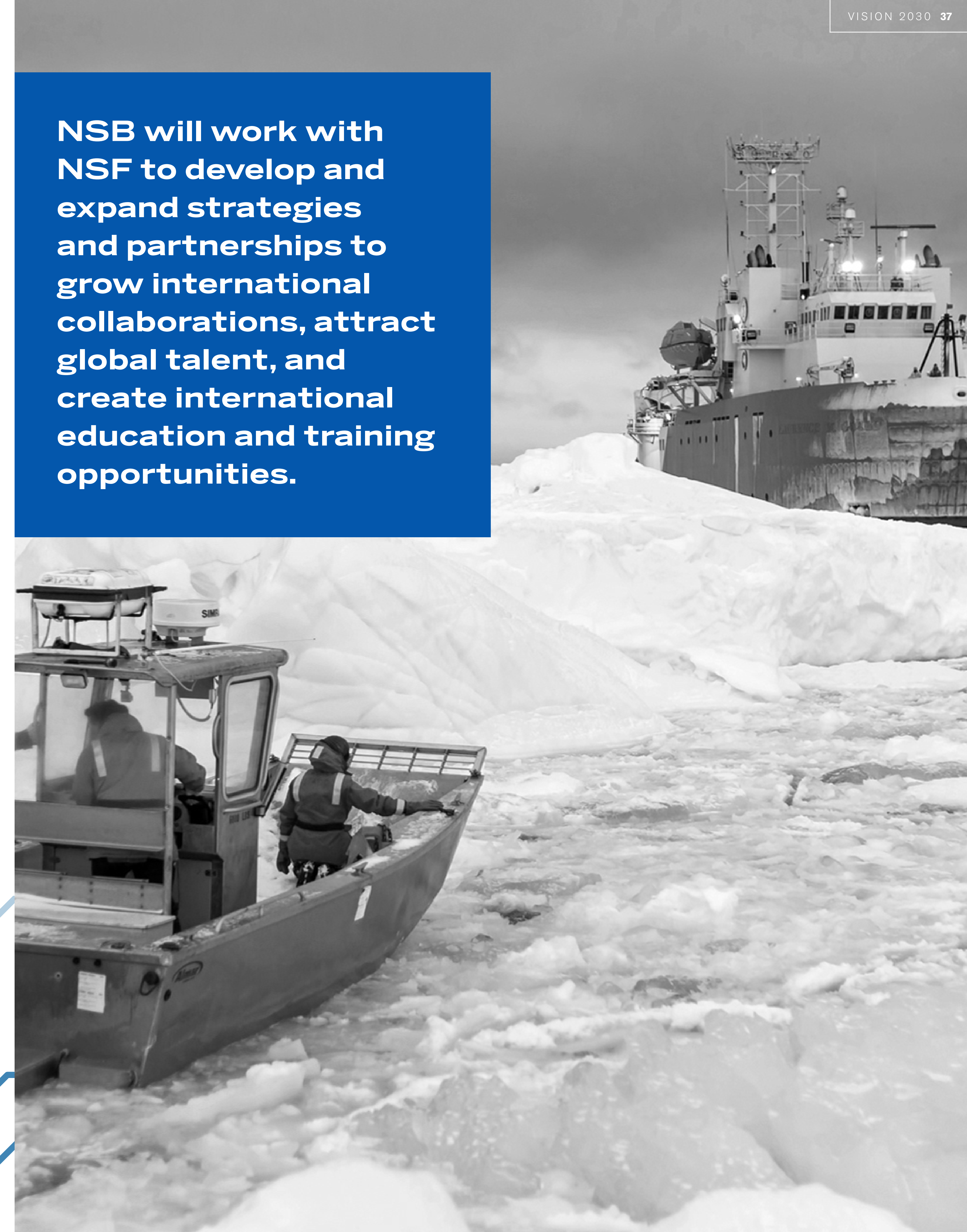
The U.S. must compete and collaborate to remain the global leader in fundamental research and provide the seed corn for innovation.

Staying at the frontiers of discovery requires leaning into internationalism, particularly given the nation's falling share of global knowledge production, paired with the rising importance and impact of international collaboration and knowledge- and technology-intensive industries.

NSB Actions with NSF:

- Continue to champion the merits of openness and the highest ethical standards in science and engineering and foster them through synergistic engagements with a global community of like-minded partners who share core values.
- Ensure NSF's participation as a reliable partner in international research collaborations to address global challenges and opportunities and build, operate, and maintain large-scale infrastructure.
- Enhance the NSF Office of International Science and Engineering (OISE), including the MULTIPLIERs program, to ensure it is well positioned to maintain awareness of the global S&E landscape and contribute to NSF's strategic planning.
- Develop and expand NSF's strategies and partnerships to grow international collaborations, attract global talent, and create international education and training opportunities.
- Work with NCSES to improve data collection on international collaborations, beyond publications.

NSB will work with NSF to develop and expand strategies and partnerships to grow international collaborations, attract global talent, and create international education and training opportunities.



ENDNOTES

1. National Science Board (NSB), "Research and Development: U.S. Trends and International Comparisons," *Science & Engineering Indicators 2020.*
2. "Knowledge and technology intensive industries" includes five high R&D intensive industries and eight medium-high R&D intensive industries. The five high R&D intensive industries are aircraft; computer, electronic, and optical products; pharmaceuticals; scientific R&D services; and software publishing. The eight medium-high R&D intensive industries are chemicals excluding pharmaceuticals; electrical equipment; information technology (IT) services; machinery and equipment; medical and dental instruments; motor vehicles; railroad and other transportation; and weapons. NSB, "Production and Trade of Knowledge and Technology Intensive Industries," *Science & Engineering Indicators 2020.*
3. Mark Muro, Jonathan Rothwell, Scott Andes, Kenan Fikri, and Siddharth Kulkarni, "America's Advanced Industries: What They Are, Where They Are, and Why They Matter," (Washington, D.C.: Brookings Institution, 2015)
4. National Center for Science and Engineering Statistics (NCSES), "National Patterns of R&D Resources: 2017–18 Data Update," (Alexandria, VA: National Center for Science and Engineering Statistics, 2020).
5. NSB, "Science and Engineering Labor Force," *Science & Engineering Indicators 2020.*
6. NSB, "Elementary and Secondary Mathematics and Science Education," *Science & Engineering Indicators 2020.*
7. NSF is an independent federal agency created by Congress in 1950 "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense..."
8. These definitions, which NSB uses in *Science & Engineering Indicators*, are similar - but not identical — to the Department of Defense definitions of basic (6.1), applied (6.2), and developmental (6.3) research.
9. National Academies of Science, Engineering, and Medicine (NASEM), "Fostering Integrity in Research," (Washington, D.C.: The National Academies Press, 2017).
10. Notification Requirements Regarding Findings of Sexual Harassment, Other Forms of Harassment, or Sexual Assault
11. NSF, "NSF Response to the JASON Report 'Fundamental Science and Security,'" (Alexandria, VA: National Science Foundation, 2020).
12. The full text of NSDD-189 can be found at the National Archives Catalog.
13. The NSF Convergence Accelerators (C-Accel) reward high-risk, innovative thinking by multi-disciplinary teams of researchers and are aimed at accelerating convergence research that is use-inspired and directed at solutions for important national challenges.
14. NSB, *Revisiting the STEM Workforce*, (Arlington, VA: National Science Board, 2015).
15. NSB, "Diminishing Funding and Rising Expectations: Trends and Challenges for Public Research Universities", (Arlington, VA: National Science Board, 2012).
16. Organisation for Economic Cooperation and Development (OECD), Program for International Student Assessment (PISA) 2018 Results.
17. Alex Bell, Raj Chetty, Xavier Jaravel, Neviana Petkova, and John Van Reenen, "Who Becomes an Inventor in America? The Importance of Exposure to Innovation," The Equality of Opportunity Project, *The Quarterly Journal of Economics, (2018).*
18. The NSB's 2015 report "Revisiting the STEM Workforce" highlighted that unlike a linear pipeline model, a pathways approach more accurately represents the non-linear relationship between education, training, and occupation.
19. NSB, "The Skilled Technical Workforce: Crafting America's Science & Engineering Enterprise," (Alexandria, VA: National Science Board, 2019).
20. NSB, "Science and Engineering Labor Force," *Science & Engineering Indicators 2020.*
21. Ibid.
22. NASEM, "Minority Serving Institutions: America's Underutilized Resource for Strengthening the STEM Workforce," (Washington, D.C.: The National Academies Press, 2019)
23. "Industries of the Future" include Quantum Information Science, Artificial Intelligence, 5G, Advanced Manufacturing, and Biotechnology.
24. NSB, "Science and Engineering Labor Force," *Science & Engineering Indicators 2020.*
25. "Stay rate" refers to the proportion of international students who remain in the U.S. five years after completion of their terminal degree.
26. NSB, "Higher Education in Science and Engineering," *Science & Engineering Indicators 2020.*
27. The NSF Act charges the Foundation with avoiding "undue concentration" of research.
28. NSB, *Bridging the Gap: Building a Sustained Approach to Mid-scale Infrastructure and Cyberinfrastructure at NSF*, (Alexandria, VA: National Science Board, 2018).
29. NSB, "Publications Output: U.S. Trends and International Comparisons," *Science & Engineering Indicators 2020.*
30. Ibid.
31. Ibid.
32. NSB, "Academic Research and Development," *Science & Engineering Indicators 2020.*

AFTERWORD

Dear Colleagues:

On the eve of the 70th anniversary of the National Science Foundation (NSF), the National Science Board (NSB, Board) has set a vision for the agency and the broader United States (U.S.) science and engineering (S&E) enterprise over the next decade and beyond. In developing Vision 2030, the NSB spent a year examining data, revisiting internal and external reports, and consulting with S&E community members across the country. We gained insights from students, early-career and seasoned professors and researchers, and administrators from a variety of institutions; inventors and representatives of academic and scientific associations; NSF staff; and others. We undertook our work on Vision 2030 with full consideration of NSB's dual role as NSF's policymaking board and independent S&E policy advisor to both Congress and the President.

Vision 2030 provides a guide to where the Board believes the U.S. S&E enterprise must be in 10 years. It identifies trends and presents a call to action in four key areas: Practice of Science and Engineering, Talent, Partnerships, and Infrastructure. It includes a roadmap for how the U.S. can reinvent aspects of its S&E enterprise to remain preeminent, including specific actions the NSB commits to taking over the next decade to contribute to this reinvention.

It is the NSB's vision that in 2030 the U.S. remains a global leader, offering unparalleled opportunities for students, researchers, STEM-capable workers, and entrepreneurs, and setting the standard for research performance, ethics, and values. Realizing this vision will require the participation of all of the entities in the American S&E ecosystem, including NSB and NSF. We hope that Vision 2030 inspires the actions our country needs.

Sincerely,

Diane L. Souvaine

Chair, NSB

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ACKNOWLEDGEMENTS

The National Science Board wishes to thank the many individuals who gave their time and thoughtful input to Vision 2030.

The Board thanks Roger Beachy, who chaired the Vision 2030 Task Force, and Task Force members Ellen Ochoa (Task Force Vice Chair), Vicki Chandler, Robert Groves, Julia Phillips, and Maria Zuber, who led the development of Vision 2030 on the Board's behalf. The NSB would also like to acknowledge Board Chair Diane Souvaine for her support and leadership on this project and former NSF Director France Córdova for her valuable insights throughout the process.

The Board acknowledges the NSF program officers, division leaders, and Assistant Directors who graciously shared their thoughts and expertise on the future of NSF and the S&E enterprise. We are also grateful for the insights and energy of Karen King, a valued Executive Secretary to the NSB, who unexpectedly passed away in late 2019. We also thank Mary Koskinen, NSF Senior Staff Associate and an Executive Secretary to the Board, for supporting several listening sessions. We extend our deep thanks to Arthur Lupia, Assistant Director of the Social, Behavioral, and Economic Sciences Directorate, who was instrumental in clarifying and strengthening Vision 2030's message and content.

Vision 2030 benefited enormously from the many college and university students, early and later career faculty and researchers, and administrators and representatives from philanthropies, industry, and scientific and university associations who shared their insights with the Task Force. We are grateful to all who participated in the listening sessions we held at Arizona State University, Dakota State University, Georgetown University, University of the District of Columbia, the National Academy of Inventors meeting in Houston, Texas, the Santa Fe Institute, Tufts University, and Washington University. Our thanks also to NSF's Advisory Committee members for participating in a listening session with the Task Force.

NSB also expresses its sincerest thanks to the entire National Science Board Office staff for their tireless support of the Board throughout the development of Vision 2030. Brandon Powell, Kyscha Slater-Williams, and American Association for the Advancement of Science (AAAS) S&T Policy Fellow Mateo Muñoz helped organize and staff our listening sessions. Chris Blair proofread the final draft of this report. Jack Meszaros, Portia Flowers, AAAS S&T Policy Fellow Michelle McCrackin, and National Research Traineeship Fellow Ed Higgins supported the report drafting and production. Brad Gutierrez and Elise Lipkowitz played leading roles in the development and drafting of the report from its inception. Nadine Lymn and Reba Bandyopadhyay provided editorial contributions and communications insights throughout the project. Kathy Jacquart served as the liaison to the Task Force and guided the steps of the Vision's development from start to finish with skill and dedication. Finally, we thank John Veysey for his guidance and the many roles that he has played in ensuring the Task Force's success.

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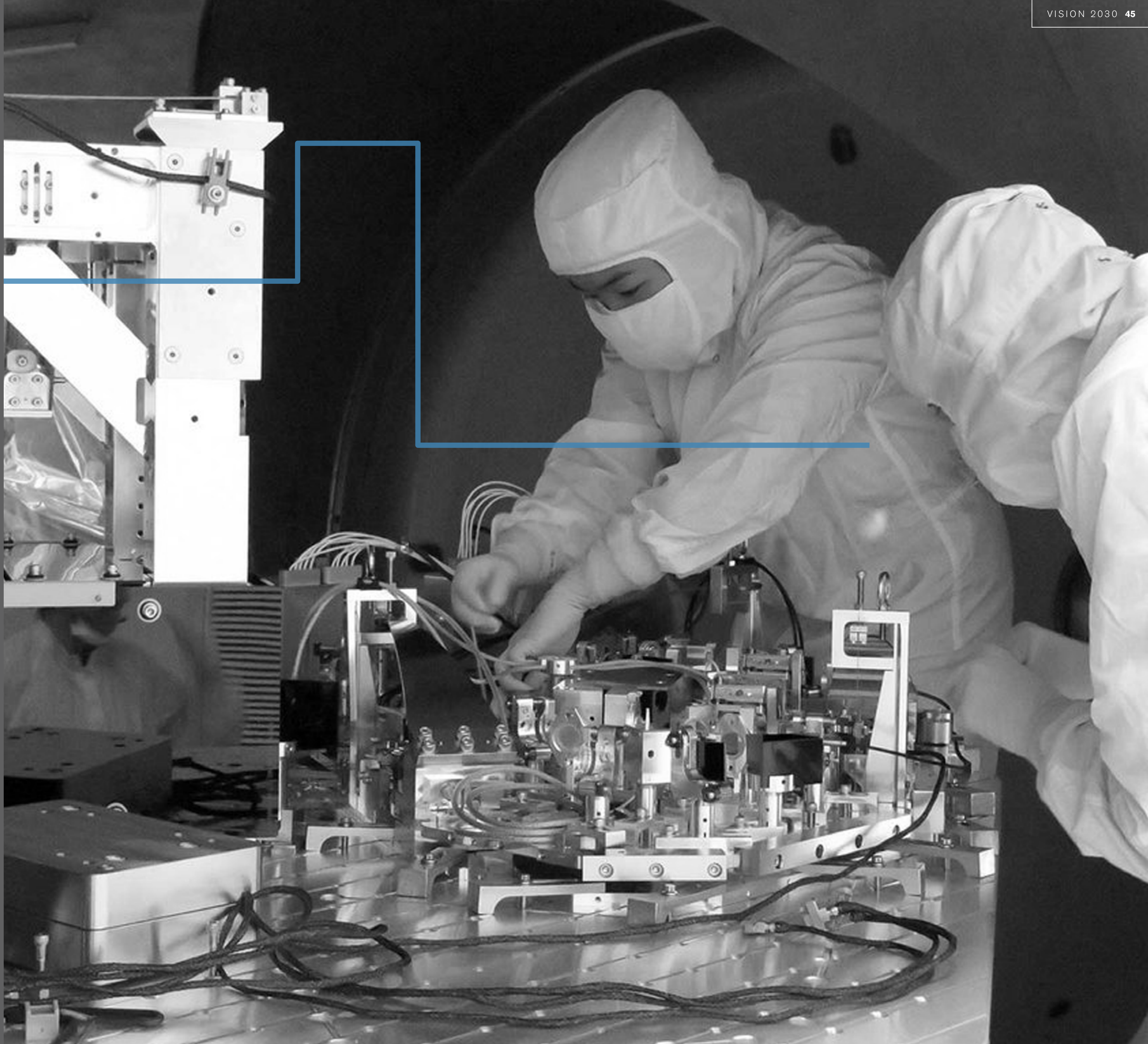

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