

The logo for the IDA (Innovation and Development Agency) consists of the letters 'IDA' in a bold, white, sans-serif font. The letters are underlined with a thin white line.

SCIENCE AND
TECHNOLOGY
POLICY INSTITUTE

REPORT TO THE PRESIDENT FISCAL YEAR 2021



The Institute for Defense Analyses is a nonprofit corporation that operates three Federally Funded Research and Development Centers. Its mission is to answer the most challenging U.S. security and science policy questions with objective analysis, leveraging extraordinary scientific, technical, and analytic expertise.

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LETTER FROM THE DIRECTOR

Dear Mr. President:

On behalf of the IDA Science and Technology Policy Institute (STPI), it is my pleasure to present our congressionally mandated report of activities for fiscal year 2021. As a federally funded research and development center, we are uniquely positioned to provide the Executive Office of the President with in-depth, objective, fact-based analyses on a wide variety of science and technology topics and trends, with complete discretion and free of conflicts of interest.

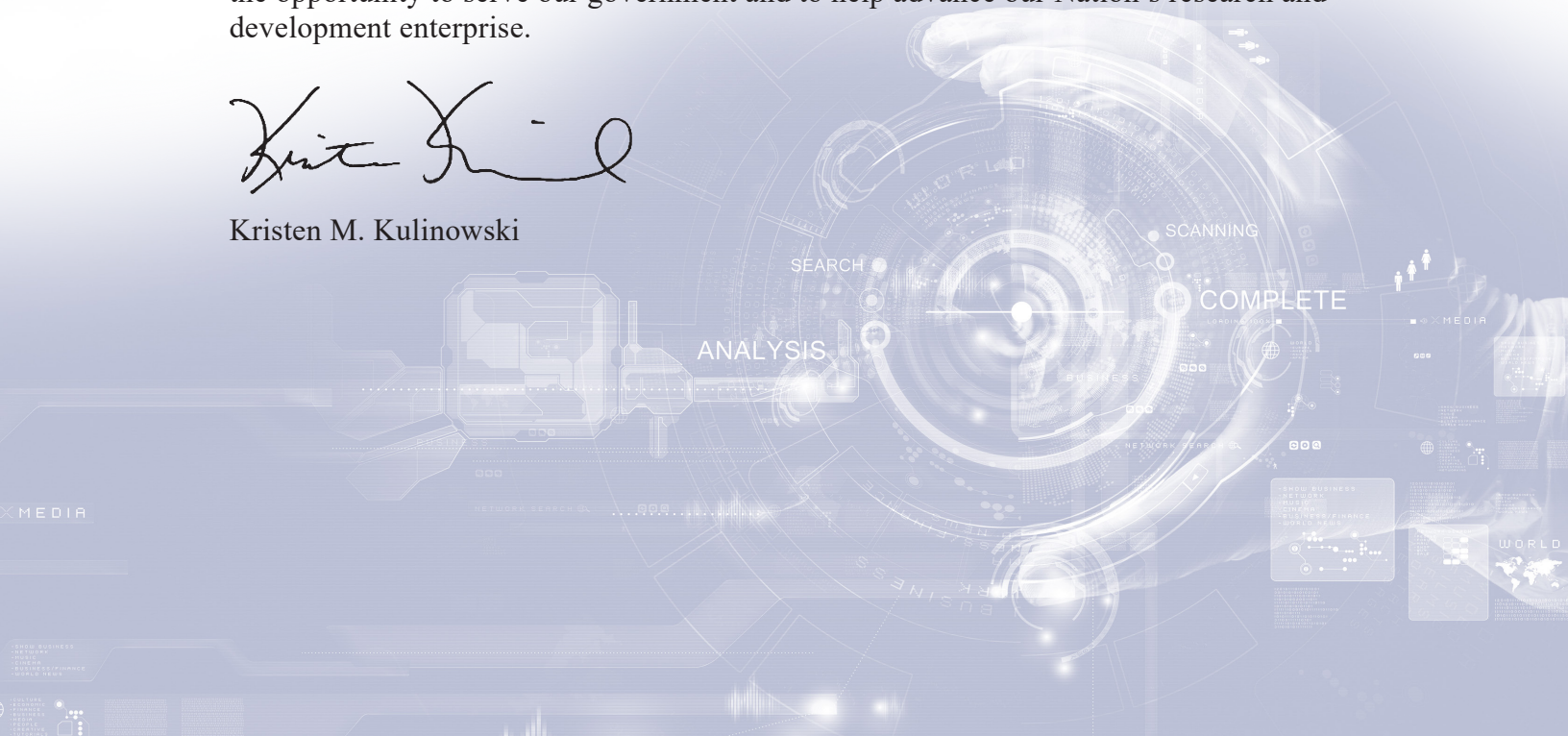
STPI was established by Congress in 1991 to inform policy development within the Office of Science and Technology Policy. In 1998, Congress expanded STPI's mission to include reporting on significant trends and developments in science and technology in the United States and abroad; analyzing those trends with attention to the Federal science and technology portfolio; and performing analyses that will help ensure the long-term strength of American science and technology. Since 2003, STPI has been operated by the nonprofit Institute for Defense Analyses (IDA) with sponsorship through the National Science Foundation.

Providing scientific and technical analysis to the Executive Office of the President is our primary mission, but we also work with other Federal Government organizations to inform science and technology policies and assess their effectiveness, including the National Science Foundation, the National Aeronautics and Space Administration, the National Institutes of Health, the Department of Commerce, the Department of Energy, the Department of Homeland Security, and the Department of Transportation.

I am proud to deliver this report showing off the depth of knowledge at STPI and the diversity of issues our team has tackled over the past year. We are deeply committed, both individually and as an institution, to keeping America at the forefront of scientific discovery and ensuring that American science and technology continues to lead the world in innovation and technical progress. On behalf of my colleagues, I thank you for the opportunity to serve our government and to help advance our Nation's research and development enterprise.



Kristen M. Kulinowski



ABOUT THE SCIENCE AND TECHNOLOGY POLICY INSTITUTE

The Science and Technology Policy Institute (STPI) was established by Congress in the National Defense Authorization Act for Fiscal Year 1991 (P.L. 101-510) 1991 as a federally funded research and development center (FFRDC) under the name Critical Technologies Institute. In 1998, Congress renamed the Institute as part of the National Science Foundation Authorization Act of 1998 (P.L. 105-207), which also assigned STPI the following duties:

- Assembly of timely and authoritative information regarding significant developments and trends in science and technology research and development in the United States and abroad.
- Analysis and interpretation of the information with particular attention to the scope and content of the Federal science and technology research and development portfolio as it affects interagency and national issues.
- Initiation of studies and analyses of alternatives available for ensuring the long-term strength of the United States in the development and application of science and technology.
- Provision, upon the request of the Director of the White House Office of Science and Technology Policy (OSTP), of technical support and assistance
 - to committees and panels of the President’s Council of Advisers on Science and Technology, and
 - to interagency committees and panels of the Federal Government concerned with science and technology.

Consistent with congressional direction, STPI provides analyses of significant science and technology policies and developments in the United States and abroad for OSTP, its primary sponsor, and for other Federal Government organizations with science and technology responsibilities. To ensure the continued relevance of its work, STPI meets frequently with the Director and staff of OSTP. Such close coordination—coupled with a flexible tasking process—ensures that STPI focuses on OSTP’s top priorities and emergent problems.

To address STPI’s broad science and technology charter, STPI researchers possess educational training and professional experience across the spectrum of disciplines and sectors. The majority of degrees among STPI’s research staff are in mathematics, physical and life sciences, and engineering, with law, social science, communication, and history rounding out the staff’s educational background.

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FEDERAL SCIENCE AND TECHNOLOGY POLICY



Design and Evaluation of Industrial Policies

The United States is making large investments in supply chain security, manufacturing institutes, and on research and development (R&D) for critical technologies, as described in Executive Order 14017 (*America's Supply Chains*), issued February 24, 2021, as well as in the CHIPS and Science Act. While the United States has previously employed strategic efforts to develop specific areas of the economy, so too have other countries. The Office of Science and Technology Policy (OSTP) asked the Science and Technology Policy Institute (STPI) to review how the United States and other countries have collected information from stakeholders and designed industrial policies and procedures to evaluate these policies. STPI identified effective processes to better design and evaluate innovation and industrial policies for three types of policies: (1) selecting critical technologies and industries, (2) designing and operating effective manufacturing institutes, and (3) ensuring supply chain resilience and security. The final report, *Successful Processes to Design and Evaluate Industrial and Innovation Policies*, focused particular attention on how to effectively collect information from stakeholders to better design such policies. The report was written to provide guidance to OSTP as it assists the Administration in designing effective policies in these areas.

Committee on Foreign Investment in the United States

The Committee on Foreign Investment in the United States (CFIUS) reviews foreign investments in U.S. companies that may pose national security concerns. STPI works with OSTP to inform their implementation of CFIUS legislation, ongoing review of filings, and workflow.

President's Council of Advisors on Science and Technology

The President's Council of Advisors on Science and Technology (PCAST) is an advisory group of leading scientists and engineers drawn from a variety of nongovernmental sectors—industry, academia, and nonprofits—who advise the President and Executive Office of the President. PCAST provides policy recommendations and guidance in areas where understanding of science, technology, and innovation is key to strengthening the American economy and creating policy that works for the American people. OSTP asked STPI to provide technical support to PCAST in the form of information gathering and assessment, technical writing and editing, and project management, as needed. STPI helped prepare the January 2021 PCAST Report, *Industries of the Future Institutes: A New Model for American Science and Technology Leadership*. STPI continued to provide support to the new PCAST established in summer 2021, providing memoranda containing statistics and analysis in response to information requests from PCAST working groups.

Science and Technology Strategies of U.S. Allies and Partners

Technological innovation is central to the future success and competitiveness of the United States. OSTP asked STPI to identify and assess strategies used by U.S. allies and partners to accelerate innovation, develop and maintain human capital, and promote and protect a country's competitive advantages. Specific technologies of interest include artificial intelligence (AI), biotechnology, quantum information sciences, green technologies, and digital governance. OSTP asked STPI to identify and synthesize science and technology strategies from U.S. ally and partner countries as well as multilateral initiatives (e.g., EU, G-7, NATO) and to identify specific recommendations and ideas listed in these strategies.

Using Bibliometric Indicators to Evaluate Science and Technology

Statistical analysis of databases covering scientific and technology journal publications are often used as metrics to judge not only the innovativeness and importance of individual researchers within a discipline, but also the prowess and status of a country's science and technology contributions to global knowledge generation. Depending on the way the metrics are calculated, the relative importance of an individual or a country can vary greatly. This variation can mask the impact of long-term policy investments in domains such as talent development through education initiatives and immigration; funding for research and engineering; and legal and intellectual property controls. Furthermore, it may possibly provide a distorted picture of impact from the spectrum of major, middling, and minor contributors to the global scientific commons. OSTP asked STPI to review existing bibliometric indicators, examine what part of the impact spectrum they may represent, and explore whether new metrics offer enhanced utility to better evaluate and identify which individuals are at the influential leading edge of science.

Improving National Resilience through Science and Technology Innovation

In May 2019, the National Science and Technology Council's (NSTC) Committee on Homeland and National Security established an interagency subcommittee that focuses on strengthening and promoting national resilience against threats and hazards that could have catastrophic consequences to national essential functions. A primary purpose of this group, the Subcommittee on Resilience Science and Technology (SRST), is to coordinate and improve Federal science and technology innovation and utilization through policy and practice. STPI provided dedicated analysis and support to OSTP in conceptualizing, planning, and completing numerous SRST deliverables aimed at increasing national resilience through Federal science and technology coordination and innovation. In 2021, STPI continued to develop a framework to investigate the interdependencies among societal dimensions of resilience and to identify the critical gaps that impede resilience. The framework, which will be piloted by SRST Member Agencies, aims to identify mechanisms to align current and future resilience science and technology capabilities to address those gaps across multiple

disruptions, resources and enablers, functions, and societal dimensions to help communities advance their own resilience. STPI also finalized an approach to assess protocols and after-action reports from both exercises and real-world events to identify resilience science and technology gaps and spot opportunities to incorporate resilience science and technology into future events and incidents.

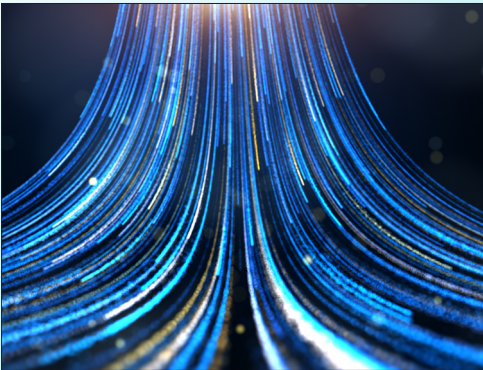
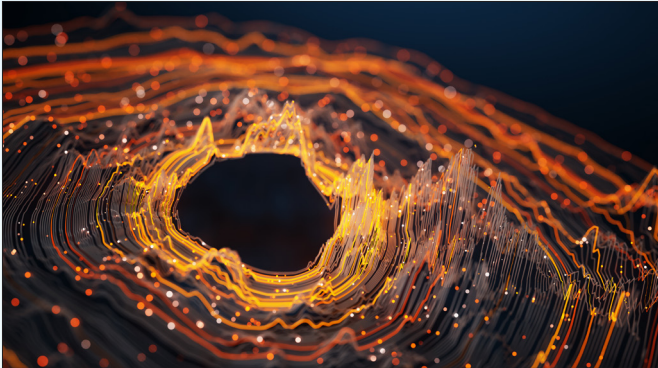
Assessing Control of Dual-Use Technologies

Export controls on dual-use technologies have recently been made more robust, including the Export Control Reform Act of 2018. The U.S. Government has placed a new emphasis on working with partners and allies as a means of further strengthening the security around exports of sensitive materials. One obstacle to this strategy has been a lack of knowledge about the extent and limitations of domestic authorities in partner countries to control sensitive exports. OSTP asked STPI for help to inform U.S. decision makers about the legal capacities and constraints on cooperation on export controls among Wassenaar Arrangement Participating States (WAPS). The resulting report was designed to provide U.S. officials involved in negotiating agreements on export controls on dual-use technologies with a comprehensive review of the laws in partner countries concerning partner country export controls. It identified areas of flexibility and unilateral control available to allies and partners, as well as areas of statutory inflexibility that may limit what they can do. The report focuses on priority countries among the European Union Member States, the United Kingdom, Japan, and South Korea—and also Israel and Taiwan, which are not members of WAPS.

Restoring Trust in Government through Scientific Integrity and Evidence-Based Policymaking

In January 2021, the President issued the “Memorandum on Restoring Trust in Government through Scientific Integrity and Evidence-Based Policymaking.” This Presidential memorandum affirmed that it is the policy of the Administration “to make evidence-based decisions guided by the best available science and data” that are not “distorted or influenced by political considerations.” The President also asked OSTP to constitute an interagency task force on scientific integrity within the NSTC to review the effectiveness of scientific integrity policies across the Federal Government. STPI assisted the task force by facilitating listening sessions with agency leads, preparing stakeholder engagement plans, assisting in the preparation and analysis of a Request for Information (RFI), coordinating with agency leads on review of the impact of inclusion practices on scientific Federal advisory committees, compiling agency publications on scientific integrity policy, and supporting the completion of the final report, *Protecting the Integrity of Government Science*.

FEDERAL DATA AND RESOURCES



Scientific Collections for the 21st Century

Scientific collections are a fundamental part of the Nation's R&D infrastructure. OSTP asked STPI to assist the Interagency Working Group on Scientific Collections (IWGSC) in preparing a new report, *Scientific Collections for the 21st Century*, summarizing how the evolving science and technology landscape is affecting the management and use of scientific collections, highlighting new recommendations for valuing Federal collections, and outlining the current priorities of the IWGSC. STPI assisted the IWGSC by helping draft the main body of the report; hosting writing team planning meetings; supporting the agency clearance process for 23 vignettes featuring individual Federal collections; and managing the internal IWGSC clearance and revision process.

Implementing Federal Prizes, Competitions, and Crowdsourcing and Citizen Science

The America COMPETES Reauthorization Act of 2010 (COMPETES) amended Section 24 of the Stevenson-Wydler Technology Act of 1980 with a new provision on prize competitions that granted broad authority to all Federal agencies to conduct competitions to spur innovation and ingenuity by permitting incentives to invite fresh perspectives, novel approaches, and collective problem-solving. The American Innovation and Competitiveness Act, which became law in January 2017, contained the Crowdsourcing and Citizen Science (CCS) Act, which gave Federal agencies broad authority to use crowdsourcing—and specifically citizen science—to advance agency missions and facilitate broader public participation in the innovation process. OSTP is legislatively required by these Acts to submit a biennial report to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives on the activities carried out under these two authorities. STPI helped compile prize competition data as well as federally conducted CCS projects for FY19 and FY20. In addition to compiling all Federal prize competition and crowdsourcing/citizen science activities in that period, STPI entirely revised the data collection process to allow more rigorous analysis of relationships among the submissions as well as reduce the effort required by each agency to prepare a submission.

Public-Private Partnerships to Develop a Microelectronics Commons Infrastructure

In June 2017, the Defense Advanced Research Projects Agency (DARPA) announced the Electronics Resurgence Initiative (ERI) in response to several technical and economic trends in the microelectronics sector. Although ERI has produced notable results over the past 4 years, there remained significant concern about the Nation's ability to transition innovative electronics R&D from the commercial sector into defense use. DARPA therefore sought to expand ERI to better enable domestic semiconductor innovations and their adoption for national security applications by establishing a prototyping infrastructure for 3DHI (3-dimensional heterogeneous

integration) components through a public-private partnership. This prototyping infrastructure could provide domestic semiconductor facilities and resources accessible by the defense base, major companies, startups, and universities. To help ensure its success, DARPA asked STPI to prepare an analysis of relevant prior public-private partnerships to identify lessons that can be leveraged to formulate the governance, structural, and operational objectives for the prototyping infrastructure. STPI's report included in-depth case studies on existing and past public-private partnerships and identified three potential models for future efforts.

Technology Transition Policy

The Department of Energy's (DOE) Office of Technology Transitions (OTT) is responsible for developing and overseeing delivery of DOE's strategic vision and goals for technology commercialization and engagement with U.S. industry. It provides coordination, oversight, and organizational structure to foster continuity in the development and implementation of policies and procedures related to the commercialization and deployment of technology and capabilities funded by DOE. OTT asked STPI to analyze current DOE and other Federal Government policies governing commercialization and technology transfer, examine relevant governmental contracting procedures and commercialization practices and processes, support OTT strategic planning and implementation efforts, and provide input and make recommendations on Federal agency policies and practices to facilitate technology commercialization and enhance DOE partnering mechanisms. STPI conducted more than 50 listening sessions with DOE staff—across research program offices, policy offices, general counsel, and field offices—to identify policy recommendations for enhancing the use of the other transaction authority to enable more effective partnerships for research, development, demonstration, and deployment activities. STPI's report identified 10 policy recommendations and associated implementation steps. STPI is now helping with implementation of policy recommendations, including establishing an internal cross-programmatic working group, identifying opportunities for legislative and regulatory revisions, identifying needs for establishing new guidance and internal agency policy, and advising on training materials and other ways to increase contracting officer capability.

Transitioning Artificial Intelligence and Nanotechnology from Lab-to-Market

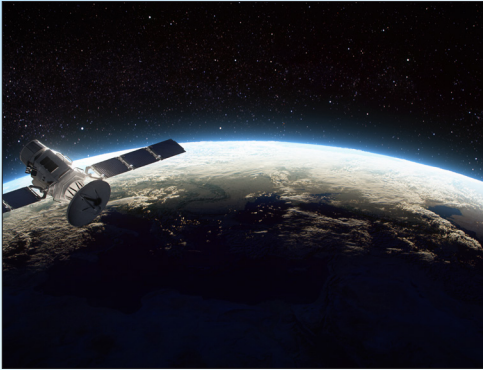
The National Institute of Standards and Technology (NIST) has set a goal of improving technology transfer and commercialization of the Nation's \$150 billion annual investment in R&D. As part of this initiative, NIST asked STPI to provide research as well as technical and analytical support to assess—quantitatively and qualitatively—the role and impacts of Federal R&D and technology transfer investments in the development of AI and nanotechnology. To achieve these goals, STPI gathered data and metrics on Federal R&D investments, R&D activities, and technology transfer activities—such as publications, patents, licenses, collaborative agreements,

workshops and conferences—focusing on historical and downstream outcomes of R&D investments in AI and nanotechnology. STPI collected information and data using a two-pronged approach: (1) a forward-looking approach in which the impacts of individual researchers and organizations that have received Federal funding are identified and tracked over time, and (2) a backward-looking approach in which the history of AI and nanotechnology-related technologies already on the market are analyzed to identify those that have had significant impacts in the scientific field and industry and to understand the Federal role in their development.

Lab-to-Market Cross Agency Priorities

The Federal Government invests approximately \$150 billion annually in R&D conducted at Federal laboratories, universities, and other research organizations. NIST, OSTP, and DOE co-chair NSTC’s Lab-to-Market Subcommittee, whose mission is to improve the transition of federally funded innovations from the laboratory to the marketplace, develop and implement more effective partnering models and technology transfer mechanisms for Federal agencies, and enhance the effectiveness of technology transfer by improving the methods for evaluating the return-on-investment and economic and national security impacts of federally funded R&D. At OSTP’s request, STPI assisted the Lab-to-Market Subcommittee in guiding strategy teams, identifying new milestones through FY23, and articulating priorities for coordination and technology transfer investments across the Federal lab-to-market community. STPI contributed to the development of the lab-to-market action plan and the preparation of a lessons-learned analysis for Federal technology transfer based on the national response to the COVID-19 pandemic. STPI also prepared a lessons-learned report about prize implementation and reviewed ways to improve measures and metrics for the evaluation of Federal technology transfer.

SPACE TECHNOLOGY AND POLICY



Microgravity Research and Development

The National Aeronautics and Space Administration (NASA) has been the primary facilitator of microgravity R&D for decades, but with the growth of commercial space companies, falling costs in some R&D fields, and the planned upcoming transition from the International Space Station (ISS) to commercial space stations in low-Earth orbit, many aspects of the microgravity R&D enterprise are changing. OSTP asked STPI to assess the microgravity R&D landscape to recommend future R&D priorities, identify barriers to conducting R&D, and suggest policy solutions to overcome those barriers. STPI conducted interviews with stakeholders in many scientific fields as well as commercial facility operators and ISS management. STPI leveraged the proceedings from the National Space Council's (NSpC) Microgravity Roundtable in October 2020 to examine the whole-of-government response needed to streamline the enterprise and maximize the Nation's investment in microgravity R&D. In FY2021, STPI prepared an updated version of this 2020 report for public release and provided a briefing for new OSTP leadership in order to inform emerging OSTP efforts in this area.

Forecasting and Mitigation of Space Weather Risks

Space weather encompasses a wide array of phenomena that have the potential to disrupt and destroy technology and infrastructure critical to the Nation's security and economy as well as challenge the security and resilience of exploration and economic activities in space. In October 2020, the Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow (PROSWIFT) Act became law, requiring OSTP, among other stakeholder executive branch agencies, to complete activities to improve the ability of the United States to forecast space weather events and mitigate their effects. In addition to general support for the development and advancement of space weather policy, OSTP asked STPI to conduct an initial assessment of the feasibility, requirements, and challenges to update Space Weather Scales and an initial review of the feasibility of and challenges to improving current space weather benchmarks, which specify the nature and intensity of extreme space-weather events and provide a point of reference from which to improve understanding of their effects.

National Planetary Protection Policy

As the number of return missions to other bodies in the solar system has increased over time, the risk of carrying terrestrial contaminants to extraterrestrial bodies as well as bringing contaminants back to Earth has become an increasingly pressing issue. STPI was asked to support OSTP and an NSTC working group in fulfilling the *National Strategy for Planetary Protection*, which was released by NSpC and OSTP in December 2021. As part of the overarching objective to conduct an independent assessment of the process, challenges, and opportunities associated with ensuring planetary protection, STPI provided technical support to the NSTC working group and assisted OSTP in hosting a workshop for the space industry. STPI helped prepare documents and reports,

including an assessment of activities outside the United States related to extraterrestrial sample return and planetary protection protocols, and maintained a dashboard for OSTP to use to monitor progress to achieve the strategic goals.

Lunar and Cislunar Economy

NASA intends to launch American astronauts to the Moon by 2024, complete construction of a habitable platform in cislunar orbit by the end of the current decade, and prepare human exploration missions to Mars in the coming decades. These efforts as well as demand driven by the international and private sector will be significantly supported by commercial space companies that will provide the required spacecraft, components, and services. To advance NASA's interest in encouraging activities supported by non-government revenue on the lunar surface and cislunar orbit, NASA asked STPI to develop a model describing current and future lunar and cislunar market supply and demand drivers; catalog the set of actors engaged in lunar activities and characterize their current strategies, motivations, and business plans; and estimate potential levels of government and non-government demand for various lunar activities.

Orbital Outposts

The Defense Innovation Unit (DIU) of the Department of Defense has begun projects to create orbital outposts and a multi-orbit logistics capability. DIU asked STPI to evaluate the combined logistical needs, synergistic technologies, and future scale of demand for activities in Earth orbit now and cislunar space in light of anticipated civil and commercial demand. Based on a review of available resources outlining the orbital outpost concept and accounting for relevant demand drivers (government-funded projects, commercial ventures, defense priorities, and international partner interests and priorities), STPI developed a model describing current and future orbital, lunar, and cislunar market supply and demand, cataloged the current set of actors engaged in logistics and in-space hosting (suppliers) and projects and ventures in space (customers), and estimated the level of government and non-government demand for various logistical and hosting activities.

Non-Federal Investment for Lunar Sustainability

NASA plans to launch American astronauts to the Moon by 2024, develop a sustainable lunar surface presence, and prepare for human exploration missions to Mars. NASA's Space Technology Mission Directorate (STMD), through their Lunar Surface Innovation Initiative (LSII), aims to spur the creation of novel technologies needed for lunar surface exploration and accelerate the technology readiness of key systems and components. LSII has identified the following six capability areas that must be matured for sustainable lunar operations: in-situ resource utilization, surface power, dust mitigation, extreme environments, extreme access, and excavation and construction. Recognizing that NASA is currently the only customer for lunar services, STMD wants to understand the minimum government commitment to the LSII capability areas that will create a value proposition sufficient for industry to invest their own resources into

a sustainable lunar economy. NASA asked STPI to analyze economic issues associated with the development of lunar infrastructure using commercial partners with the objective to propose options for NASA-wide investment in lunar surface capabilities that may encourage co-investment from non-Federal participants. STPI evaluated the contours of supply and demand for each of LSII's six lunar surface capabilities of interest. In addition to describing the business case considerations for companies in this nascent market, STPI also developed a framework for assessing the effectiveness of various NASA actions for attracting private co-investment, thus reducing overall government costs of lunar exploration.

National Space Policy and Strategy

In response to congressional reporting requirements included in the Fiscal Year 2021 National Defense Authorization Act, NSpC asked STPI to (1) prepare a report on options for strengthening U.S. civil and national security space capabilities and (2) prepare a report assessing the relative space capabilities of the United States and China. For the report on strengthening U.S. space capabilities, STPI recommended (1) preparing a 10-year roadmap for civil space programs to leverage commercial gains in space capabilities, (2) increasing partnerships with allies of the United States, (3) ensuring a robust and secure supply chain and manufacturing processes while sustaining a skilled workforce and leadership capabilities in support of U.S. space capabilities, (4) ensuring freedom of navigation of space from potential adversaries, and (5) enhancing resilience of civil and national security space operations. The second report provided a comparative assessment of U.S. and Chinese capabilities with respect to human exploration and spaceflight, exploitation of space-based resources (including minerals and solar power), and current and future space launches. In addition, the report evaluated the extent of foreign investment in the commercial U.S. space sector, the ability of the Department of Defense to mitigate threats to commercial communications and navigation, Chinese malign activities (theft of U.S. intellectual property and efforts to seize control of critical supply chain elements) in the space sector, and efforts by China to pursue cooperative agreements with other nations. The report also identified gaps in authorities to address threats by China to the U.S. space sector.

Space Orbital Debris

In the last 60 years, human activity in space has generated over 34,000 objects sized greater than 10 cm in diameter, more than 900,000 between 1 cm to 10 cm, and 128 million objects between 1 mm to 1 cm. The growing amount of debris increases the probability of collisions with other objects, and while the risk of individual collisions is relatively low, each one generates new debris that can greatly increase the likelihood of another collision. Cascading growth of debris introduces challenges to the sustainability, safety, stability, and security of the outer space environment, and represents a threat to both human and robotic space flight. OSTP asked STPI to critically examine the challenge of orbital debris, with a focus on understanding the R&D gaps to minimize the creation of debris, as well as to track, mitigate, and

remediate it. STPI supported an interagency working group whose goal is to develop an implementation plan to the Orbital Debris R&D Strategic Plan that was published in January 2021 by NSTC. STPI helped convene several activities to gather input from the broader community about orbital debris actions including a request for comment on the National Strategy, two virtual public listening sessions, and an academic workshop. STPI has collated, harmonized, and drafted a list of implementation actions for the agencies to prioritize and consider taking to address the challenges of orbital debris.

Global Norms of Behavior and Legal Regimes Related to On-Orbit Activities

Understanding individual countries' attitudes toward norms of behavior in space—namely, how various countries perceive and act on them—is imperative to protect orbital national security operations and enhance space sustainability in a future where there will be a larger number of actors, public and private, in various orbits in near-Earth and deep space. As the number of countries involved in space increases, the importance of clear definitions on proper behavior increases. Knowledge of how key countries develop policies and actions related to operating in space is vital to understanding how global norms will evolve in the future. STPI examined the legal, policy, and technical considerations for on-orbit servicing, assembly, and manufacturing (OSAM) and how they may change in the future as space activities become more diverse. STPI found that most countries and companies do not have a common definition of what a norm of behavior in space is, and that new activities, such as OSAM, do not have enough heritage for norms to develop.



STEM EDUCATION, WORKFORCE, AND TALENT POOL



Benefits and Costs of Foreign STEM Talent in the United States

To help inform policy decisions by the Federal Government concerning the admission of foreign students and workers to the United States, OSTP asked STPI to make a comprehensive, empirically-based comparison of the potential economic benefits and costs to the United States related to foreign science, technology, engineering, and mathematics (STEM) talent who visit, work, or study in this country. The report, *Economic Benefits and Losses from Foreign STEM Talent in the United States*, provided quantitative estimates and a net assessment of those economic benefits and costs. It has been used to support the assessment of policy shifts designed to attract and retain foreign STEM talent in the United States.

STEM Education of the Future: Challenges and Enduring Questions

The National Science Foundation's (NSF) Directorate for Education and Human Resources (EHR) seeks to achieve excellence in U.S. STEM education for all ages and in all settings. That excellence supports a well-prepared workforce of scientists, technicians, engineers, mathematicians, and educators in addition to a well-informed citizenry. Together those two audiences draw on scientific and engineering habits of mind and practice to enhance the quality of life of all citizens and the health, prosperity, welfare, and security of the Nation. STPI supported NSF's engagements with representatives of the STEM education R&D community and other STEM education stakeholders to explore possible future directions and venues for STEM learning and education. These efforts included five workshops: new and emerging methods in STEM education research, CAREER awardees (two workshops), climate science and communication, and blockchain in education. STPI also supported five listening sessions: mid-scale instrumentation for STEM education research, online STEM learning (two sessions), effects of online STEM education on educational organization, and data science education. These sessions were intended to provide information rather than make recommendations to NSF.

STEM Data Inventory

In 2018, the President issued an Executive order establishing the President's National Council for the American Worker. The Council and its Advisory Board established data working groups to identify the best use of existing data and tools to support informed decision making by American students and workers. In support of this effort, STPI assisted OSTP with numerous analytical efforts related to characterizing Federal data resources and the legal and technical landscape around Federal data sharing. In FY21, at the request of OSTP, STPI worked on a lessons-learned analysis of the COVID-19 Insights task force, a data sharing initiative between the Department of Health and Human Services, Department of Veterans Affairs, Department of Energy, and Oak Ridge National Lab (ORNL) that aims to bring together several federally held COVID-19-related data sets and use ORNL's computing power to answer key questions about

COVID-19. The final deliverable summarized the efforts of the COVID-19 Insights task force; determined major participants in the activities; and identified past, present, and anticipated activities of the task force.

Supporting Veterans in STEM Careers

The 2020 Supporting Veterans in STEM Careers Act aims to promote the involvement and equity of veterans and military spouses in the STEM workforce. The law tasks OSTP to establish an interagency working group, develop a strategic plan to identify the barriers to reentry faced by veterans and their spouses, and outline activities Federal agencies can pursue to address these barriers. OSTP asked STPI to assist in supporting the development of a strategic plan to help veterans and military spouses pursue STEM careers. STPI provided background materials and a strategic plan facilitation process for a new NSTC interagency working group on veterans and military spouses in STEM. STPI's research provided foundational information for the working group's report, *Strategic Plan to Improve Representation of Veterans and Military Spouses in STEM Careers*, which was published in December 2021.

Federal Coordination in STEM Education Subcommittee

STEM education lays the foundation for continued U.S. global leadership in discovery, innovation, and invention. As part of the America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science (COMPETES) Reauthorization Act of 2010 (H.R. 5116), OSTP was tasked by Congress with the coordination of Federal STEM education programs. STPI has supported the NSTC Federal Coordination in STEM Education subcommittee (FC-STEM) by providing technical analyses and maintaining the STEM Guiding Principles document. In FY21, STPI provided an analysis and summary of the 2020 STEM RFI. In addition, STPI supported FC-STEM in the preparation of the 2021 Progress Report on the Implementation of the Federal STEM Education Strategic Plan, which provides an update on ongoing efforts and implementation practices across the Federal Government to advance the goals and objectives of the Federal STEM Strategic Plan and budget information from all Federal agencies that have investments in STEM education during FY21.



PUBLIC HEALTH



Informing the Development of the Advanced Research Projects Agency for Health

America has an extraordinary biomedical ecosystem, which has delivered therapeutic and diagnostic advances that not long ago would have been inconceivable—such as drugs that unleash the immune system to eliminate certain cancers and COVID-19 vaccines developed and approved in only 11 months. To develop and expand the potential of rapidly transforming such breakthroughs in biomedicine into tangible solutions for patients, the Administration plans to launch a new research paradigm, the Advanced Research Projects Agency for Health (ARPA-H), as a \$6.5 billion component of the National Institutes of Health (NIH). To inform the establishment of ARPA-H, OSTP undertook a variety of efforts to engage with nonprofit and philanthropic organizations, professional societies, the academic research community, industry, patient advocates, and others to identify opportunities and barriers to accelerate biomedical and health research breakthroughs. OSTP requested STPI support to compile, summarize, and analyze comments regarding ARPA-H received through an RFI and a series of virtual stakeholder meetings. STPI's work helped to inform OSTP's deliberations regarding the establishment of ARPA-H and contributed to a report summarizing the outcome of OSTP-NIH listening sessions.

Countering Biological Incidents

As the COVID-19 pandemic response has shown, there is a critical need to provide accurate, effective, and evidence-based public health interventions in the early stages of an epidemic, while medical countermeasures are being developed and deployed. Executive Order 13994 (*Ensuring a Data-Driven Response to COVID-19 and Future High-Consequence Public Health Threats*) supports the creation of a better public health infrastructure to prevent, detect, and respond to future biological threats. OSTP asked STPI to support their Epidemic Modeling and Forecasting Fast Track Action Committee (FTAC) as they develop a Plan to Advance Data Innovation to better prepare for and respond to future pandemic threats. In support of the FTAC, STPI developed background materials, meeting resources, agendas, and summary materials for each FTAC meeting and supported the tiger teams during their deliberations. After being reviewed by NSTC and agency members, the Plan was approved and published on the White House website. This Plan will be used to guide data innovation at the National Center for Epidemic Forecasting and Outbreak Analytics.

ENVIRONMENT



Ocean Mapping, Exploration, and Characterization

In June 2020, the Ocean Science and Technology Subcommittee of the Ocean Policy Committee released the *National Strategy for Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone (EEZ)* and established the National Ocean Mapping, Exploration, and Characterization Council, with the purpose of coordinating Federal policy and actions needed to advance the objectives of the National Strategy. OSTP asked STPI to identify science and technology priorities in ocean mapping, exploration, and characterization (MEC) with the aim of informing science and technology investments by the Federal Government and non-governmental partners to spur innovation and support ocean MEC. Based on a review of current literature and interviews with personnel managing science programs who share some of the broader aims and challenges facing MEC of the U.S. EEZ, STPI prepared a report identifying three main science and technology priorities: (1) increase the use and capabilities of uncrewed platforms, (2) establish a unifying ocean informatics framework, and (3) develop AI tools to augment human effort, particularly in the analysis of biodiversity.

Meteorological Services

OSTP established the Interagency Council for Advancing Meteorological Services (ICAMS) in July 2020 to serve as the legislatively mandated Interagency Committee for Advancing Weather Services. As the new coordinating body was being stood up, STPI has helped OSTP understand the challenges and opportunities related to meteorological services at agencies and departments involved with ICAMS through analyses of publicly available budget documents and structured interviews with agency staff. To help ICAMS get off the ground, OSTP asked STPI to organize and identify goals for an interagency retreat. Over 200 attendees representing more than 20 Federal departments and agencies participated in focused breakout sessions held over 3 days. Discussion focused on defining the place of ICAMS among existing bodies (e.g., United States Global Change Research Program and United States Group on Earth Observations), identifying and addressing gaps in meteorological services for underserved communities, and establishing the cross-agency network needed for ICAMS to coordinate activities across the Federal enterprise. The report resulting from the retreat will inform the development of the strategy for ICAMS in the coming 5 to 10 years.

Satellite Needs and Earth Observation

OSTP, through the Satellite Needs Working Group (SNWG) of the NSTC's U.S. Group on Earth Observations (USGEO) Subcommittee, supports a biennial process to collect satellite measurement needs from Federal civil agencies. The objective of this process is to identify, collect, and transmit civil agency measurement requests to NASA for consideration in its systems engineering process. In 2021, STPI provided SNWG co-chairs with a descriptive summary of the responses to the 3rd Satellite Needs Survey to provide early insights into agency satellite needs.

OSTP asked STPI to support the effort of USGEO to generate a prioritized list of Earth observation systems that are likely to be at risk in the next 2–3 years, a priority action for USGEO identified in the NSTC’s 2019 *National Plan for Civil Earth Observation*. Specifically, OSTP requested STPI to analyze the 2nd National Civil Earth Observation Assessment (EOA 2016) database and identify highly connected data sources and key intermediate products.

First 100 Days Climate Change Report

Executive Order 14008 (*Tackling the Climate Crisis at Home and Abroad*) charged OSTP with writing a report highlighting climate solutions with the most benefits for air and water quality. STPI provided research support as an input in the form of a report characterizing (1) implications of greenhouse gas-emitting activities for outdoor air and fresh water quality; (2) implications of climate change for air and water quality; (3) a taxonomy and catalog of climate change strategies and technologies—spanning climate change mitigations, interventions, and adaptations—and associated air and water quality implications; and (4) context to inform integration of mitigation and adaptation solutions to optimize benefits for air and water quality. STPI found that air and water quality benefits of technologies should be considered across their full life cycle and are often unevenly geographically distributed within the United States and around the world; co-benefits of different solutions are highly context-specific; it is unlikely that any single solution can be definitively characterized as having the “most” air and water quality benefits, but those that involve reducing consumption are likely to have fewer adverse environmental impacts; economic and social factors will influence the feasibility of widespread adoption of any particular solution; and that risks of climate change are of such magnitude and urgency that no single solution will suffice.

Contaminants of Emerging Concern in Drinking Water

Contaminants of emerging concern (CECs) are newly identified or reemerging manufactured or naturally occurring physical, chemical, biological, radiological, or nuclear materials that may cause adverse effects to human health or the environment and do not have a national primary drinking water regulation. In the FY20 National Defense Authorization Act, Congress directed OSTP to develop a National Emerging Contaminants Research Initiative that would guide a CEC Interagency Working Group in coordinating Federal research programs operating in this arena. OSTP asked for STPI’s assistance to launch the working group, assist in drafting the research initiative, develop a public engagement action, and participate in the Interagency Working Group leadership team. In FY21 the first draft of the National Emerging Contaminants Research Initiative was completed, a CEC RFI developed and analyzed, and three Federal workshops to launch interagency coordination completed.



EMERGING TECHNOLOGIES



Quantum Information Science

Quantum information science (QIS) applies fundamental laws of physics to the acquisition, transmission, and processing of information in order to generate new knowledge and technologies that could expand the U.S. industrial base, provide new employment opportunities, and bolster the economy and national security. STPI prepared memoranda for the National Quantum Coordination Office that identified quantitative information that can be used to assess the National Quantum Initiative and characterize QIS R&D activities. STPI has also worked with the Subcommittee on Economic and Security Implications of Quantum Science to characterize the supply of QIS-related PhDs awarded at U.S. institutions.

Ecosystem for Critical and Emerging Technologies

NSF asked STPI to develop an ecosystem-based framework for select Critical and Emerging Technologies (CETs) and to analyze the challenges, opportunities, risks, and other factors associated with these CETs. This request originated from NSF's participation in the FTAC developing the National Security Science and Technology Strategy under the coordination of NSC and OSTP. STPI developed a generalized framework for technology maturation, and for each CET area described factors associated with the industry structure that will modify the processes of technology maturation. STPI also developed a generalized workflow for conducting CET ecosystem analyses. For each of three CET areas (microelectronics, biotechnology, and AI), STPI outlined specific factors associated with the industry structure, which were used to generate detailed visualizations of the interconnections within an ecosystem that describe how a specific technology develops within the context of that CET's industry structure. For each CET area, STPI also provided examples of how the CET ecosystem analysis workflow could be used to help inform whether policy intervention should be considered to target particular elements of the ecosystem.

Emerging Technology Supply Chain Chokepoints

Executive Order 14017 (*America's Supply Chains*) called for reviews of four technology supply chains (microelectronics, high-capacity batteries, critical minerals, and pharmaceuticals) by Federal agencies. Within those supply chains, there are some well-known examples of chokepoint technologies, such as the extreme ultraviolet (EUV) photolithography tools that are necessary for fabrication of state-of-the-art microchips and are produced by only a single company in the Netherlands. To prevent U.S. competitors—China in particular—from achieving self-sufficiency in microelectronics, the United States and its allies have used export controls and other measures to protect access to this EUV photolithography tool. OSTP and NSC are interested in understanding whether similar chokepoint technologies exist for other critical and emerging technologies, and whether they warrant additional Federal investment or additional protections (e.g., export controls or prevention of foreign investment resulting in technology transfer). OSTP asked STPI to identify whether

there is a repeatable, analytic method that can be applied to identify chokepoint technologies. STPI defined chokepoint technologies as technologies with a limited number of manufacturers located in the United States and its friend and allied countries, the absence of alternative technologies that provide similar capabilities and comparable performance, and high barriers to entry for companies that might seek to develop competing technologies. Based on a review of the scientific and commercial literature and other open source materials as well as interviews with subject matter experts, STPI developed a general method for identifying chokepoint technologies. The approach was tested and refined using case studies for three technologies that potentially pose risks to U.S. national security or economic competitiveness: multi-beam scanning electron microscopes, quantum gravimeters, and benchtop DNA synthesizers. The results of STPI's analyses are being delivered in a series of documents, one for each of the case study technologies.

National Artificial Intelligence Research Resource Task Force

The National AI Initiative Act of 2020 called for NSF, in coordination with OSTP, to form a National AI Research Resource (NAIRR) Task Force (TF) to investigate the feasibility and advisability of establishing and sustaining a NAIRR, which would serve as a national means to help democratize access to the cyberinfrastructure resources and tools that fuel AI R&D. STPI was asked to conduct background research based on review of literature, expert interviews, and examination of case studies to help inform TF deliberations about the potential design of the NAIRR system, organized according to four topics: (1) governance, ownership, and administration; (2) security requirements and user access controls; (3) testbeds and living labs; and (4) sustainment and partnership models. In FY21, STPI delivered to the TF a research paper on key considerations and options for NAIRR ownership, governance, and administration, along with associated tradeoffs, existing models and examples that could inform design decisions about the NAIRR. STPI is also supporting the TF and its working groups in development of its Interim and Final Reports.



AGENCY PROGRAM AND PORTFOLIO EVALUATIONS



Grant Writing Support Effects on Resubmission

NIH funds biomedical research through a competitive grant review process. In 2011, Ginther et al. reported a significant racial gap apparent in obtaining investigator-initiated NIH R01 grant funding. Subsequently in 2012, the NIH Advisory Committee to the Director (ACD) Working Group on Diversity in the Biomedical Sciences made a series of important recommendations to narrow this racial funding gap in R01s. These efforts were expanded upon in 2016 by a follow-up Funding Disparity Working Group (FDWG) of the ACD. Using more recent data, the FDWG found a disproportionate underfunding of some subgroups of R01 first-time applicants compared to other subgroups and that these unfunded subgroups were less likely to resubmit their applications. As a result, NIH asked STPI to design, implement, and monitor a grant writing intervention that would bring coaches from the National Research Mentoring Network (NRMN) together with NIH applicants to provide support in working toward resubmission of unfunded applications. STPI identified a control group and a cohort who would receive coaching and held a workshop and web conferences to provide support for resubmission. The first mentoring cohort was formed in 2018 and completed in 2019. A second, expanded cohort began in 2020 and was completed in 2021. NIH will use the results of the intervention to inform future grant writing support efforts.

USAID Energy Evidence and Learning Framework

USAID programs in the energy sector include a wide range of interventions such as the promotion of renewable energy development, power sector planning and operations, strengthening policy and regulatory frameworks, and building the capacity of key institutions such as utilities and government agencies. USAID's Energy Division supports this programming through thought leadership, tailored technical assistance to missions in the design of programs, and the provision of technical expertise through centrally managed mechanisms that are available for mission buy-in. STPI was asked by the Energy Division to assist in creating an Evidence and Learning Framework to help identify priority questions concerning USAID Energy programming and then present a plan to address those questions and disseminate learnings within USAID and beyond. The Framework will go beyond being a static document and instead reflect a flexible approach that can lend itself to iterative refinement as programmatic priorities are adjusted and new evidence (such as evaluations and targeted studies) is gathered. In addition, it will organize relevant information produced throughout program implementation and use it to support learning. STPI helped arrange nine workshops with USAID personnel intended to identify what participants know about successful programming and what they do not, and to define priority questions to guide future program evaluations. As part of this project, STPI wrote a learning agenda for USAID's Energy Division.

A Conceptual Framework for Conducting Themed Evaluations

The NSF Directorate for Education and Human Resources (EHR) regularly conducts evaluations of its individual programmatic initiatives; however, it has not been possible to aggregate the results across programs around key themes or issues of particular interest. EHR is interested in developing approaches to evaluation around particular themes or areas of research (referred to hereafter as “thematic assessment”). EHR tasked STPI in 2012 to develop a conceptual framework for these thematic assessments and to apply that framework to three themes: cyberlearning, pre-K–5 science education, and broadening participation research (BPR). The cyberlearning and pre-K–5 science education approaches were completed in 2014; the two documents provided operational definitions of awards associated with each area, applied those definitions to identify the NSF portfolios, and presented methodologies that could be undertaken to evaluate the themes without needing to conduct full evaluations. The final assessment, completed in 2021, focused on the portion of the portfolio administered by the EHR Division of Human Resource Development and identified an operational definition of BPR that applied to NSF awards. The assessment also determined that it is feasible to assess the publications and citations of NSF BPR projects.

National Cancer Institute Activities Related to Program Analyses and Evaluations

The Center for Research Strategy (CRS), within the National Cancer Institute (NCI) Office of the Director, is charged with analysis, assessment, and reporting on the results of NCI research programs—and the use of analyses to guide future research efforts and inform research policies. NCI requires that all new program proposals include performance or evaluation measures, and all program renewal requests include information on program evaluation results. CRS asked STPI to carry out technical analyses and evaluation studies for planning, developing, coordinating, presenting, and managing cancer research programs. STPI worked with NCI program management and stakeholders to conceptualize and define analyses and evaluations relevant to NCI cancer research programs; CRS to develop documents and training sessions for NCI staff synthesizing information from multiple analyses and evaluation studies; and CRS on analysis and evaluation tasks related to unique NCI initiatives, such as the Beau Biden Cancer Moonshot.SM In the course of this project, STPI provided literature reviews on evaluation-related topics (health impact evaluation frameworks), summarized information gathered from focus groups of NCI staff regarding future evaluation capacity needs and the role of CRS, presented a series of webinars providing training in R&D program evaluation basics, and prepared methods for a potential future evaluation of the NCI Cancer Moonshot.

Clinical Trials and Translational Research Advisory Committee Strategic Planning

In 2019, NCI convened a Strategic Planning Working Group to develop recommendations for realizing the vision for cancer clinical trials in 2030 and beyond as well as improving the operational efficiency and reducing the cost of cancer clinical trials today and in the future. STPI was asked to provide strategic and analytical support for this working group including guiding and facilitating their deliberations and drafting of the Final Working Group Report. The report, which was submitted to the NCI Clinical Trials and Translational Research Advisory Committee in late 2020, contains 15 recommendations and 3 operational initiatives that will inform the conduct of NCI clinical trials over the next decade. Following submission of the report, NCI asked STPI to assist with planning for implementation of the recommendations, including developing a detailed implementation plan and timeline, assisting NCI in determining which recommendations should have the highest priority for implementation, and beginning to gather information necessary to inform implementation of certain high priority tasks.

Emerging Frontiers in Research and Innovation Research Experience and Mentoring Program

NSF's Emerging Frontiers in Research and Innovation (EFRI) program and the Engineering Research Center (ERC) program are funded by the NSF Directorate for Engineering (NSF/ENG) to support multi- or interdisciplinary collaborations focused on transformational engineering research and technological innovations. Teams with active EFRI or ERC awards are eligible to apply for Research Experience and Mentoring (REM) supplements, which provide summer research opportunities and mentorship for high school and undergraduate students as well as high school teachers. NSF asked STPI to assess impacts of the REM supplement program on research participants, mentors, and research projects conducted by EFRI and ERC teams. STPI conducted a survey of the students who had participated in REM from 2017 to 2021 and learned how the program had been received and the impact of the program on the students' and teachers' careers. In addition, STPI analyzed annual and final reports to better understand the mentoring strategies used in the REM program. STPI found that survey respondents reported the program to have a positive impact on their persistence in STEM and their careers.

Federal Research Efforts Related to 2022–2026 Arctic Research Plan

The Arctic Research and Policy Act of 1984 called for a comprehensive national policy focused on research needs and objectives in the Arctic, and established both the Interagency Arctic Research Policy Committee (IARPC) and the Arctic Research Commission (USARC) to help implement the act. In March 2021, OSTP asked STPI to support the development of the IARPC Biennial Implementation Plan for the execution

of its Arctic Research Plan (ARP) 2022–2026. IARPC sought to identify and assess where agency activities and experience are already aligned with the ARP 2022–2026 Priority Areas (PAs) and Foundational Activities (FAs). In particular, STPI conducted an examination of previous efforts (ARP 2017–2021), interviews, and a review of the President’s Budget to assess two newly named areas of broad, crosscutting goals—Sustainable Economies and Livelihoods (PA3) and Risk Management and Hazard Mitigation (PA4)—and two FAs that were specifically named and formalized in the new plan’s framework to more effectively support, inform, and advance each of the PAs (Co-Production of Knowledge and Indigenous-Led Research [FA1] and Technology Innovation and Application [FA5]).

Transformative Research Award Anonymized Review Evaluation

NIH employs a competitive peer-review process for grant applications that aims to identify the most promising research through a review process that is fair, independent, expert, and timely. The NIH Common Fund and the Center for Scientific Review developed a multi-phased, anonymized grant review process that constrains information in the applications that would identify the principal investigators, collaborators, laboratory, or institution until the last phase of the review to reduce the potential impact of bias on the review process. Anonymized review was piloted using the FY21 NIH Director’s Transformative Research Award (TRA) initiative. NIH tasked STPI to evaluate whether anonymization impacted the review process for applicants, reviewers, and NIH administrative staff participating in the review, and whether anonymized review changed the diversity of the applicants and awardees. Using a mixed methods approach, STPI determined that the anonymized process met the NIH review criteria; anonymization was, for the most part, maintained; and there is evidence for increased applicant diversity for gender, race, and ethnicity. The analysis will be applied to the FY22 and FY23 TRA cohorts, followed by a comparison study that includes all 3 years of the pilot review process.

NIH Director’s Transformative Research Award

As a component of the NIH Common Fund’s High-Risk, High-Reward Research program, the NIH Director’s TRA initiative supports scientists who are exceptionally creative and research that has the potential to create or overturn fundamental scientific paradigms. NIH tasked STPI to evaluate research outputs from the 2010–2012 TRA awardee cohorts and determine whether the research outputs are more transformative, innovative, and impactful than research produced by comparison groups. STPI developed and implemented a multi-modal evaluation strategy that included surveys of TRA and comparison group awardees, analyses of bibliometric and altmetric data, and subject matter expert review. The results of this assessment will inform the NIH Director’s policy decisions.

