TIP ROADMAP

An Investment Strategy for the U.S. National Science Foundation's Directorate for Technology, Innovation and Partnerships
June 2024

U.S. National Science Foundation
Directorate for Technology, Innovation and Partnerships

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Executive summary

Today, global competitiveness hinges on a nation's ability to harness the power of technology. Congress recognized this driver in the "CHIPS and Science Act of 2022," in which it established within the U.S. National Science Foundation (NSF) the Directorate for Technology, Innovation and Partnerships (TIP) to "advance research and development, technology development, and related solutions to address United States societal, national, and geostrategic challenges, for the benefit of all Americans."

As part of that law, Congress charged the Director with producing a written report laying out the TIP directorate's strategic vision that will guide its initial investment decisions; how it will increase funding for research and education for populations and geographic areas underrepresented in science, technology, engineering, and mathematics; and how the directorate will protect federally funded science and technology. This inaugural TIP Roadmap does just that.

To accomplish its mission and mandate, TIP will structure each of its investments to advance one or more of the following core objectives:

Cultivate diverse innovation ecosystems throughout the U.S. to advance use-inspired research and innovation in key technologies and to address societal and economic challenges;
Advance U.S. competitiveness in critical and emerging technologies by developing and translating innovations and addressing national challenges; and
Grow a diverse and inclusive next-generation talent base and workforce around key technology and challenge areas, building expertise in necessary technical skills, use-inspired research, and innovation, entrepreneurship, and translation.

In doing so, TIP will leverage a wide range of customized funding mechanisms tailored to meet gaps in the innovation environment and address areas of highest priority and likeliest return on investment.

The "CHIPS and Science Act of 2022" set forth an initial list of 10 key technology focus areas for TIP to address through its investments. NSF assessed that these 10 technology areas remain critically important to U.S. economic and national security and elected to maintain the 10 areas listed in the legislation to guide the TIP directorate's initial investments. However, as current budget levels constrain the ability of TIP to significantly advance U.S. competitiveness in all 10 focus areas concurrently, the TIP Roadmap sets out a framework for the directorate to stage investments in the key technology areas for optimal effects on U.S. competitiveness.

Figure 1. *Key Technology Focus Areas*

1	*AI, machine learning, autonomy, & related advances*
2	*High performance computing, semiconductors, & advanced computer hardware and software*
3	*Quantum information science & technology*
4	*Robotics, automation, & advanced manufacturing*
5	*Natural & anthropogenic disaster prevention or mitigation*
6	*Advanced communications technology & immersive technology*
7	*Biotechnology, medical technology, genomics, & synthetic biology*
8	*Data storage, data management, distributed ledger technologies, & cybersecurity, including biometrics*
9	*Advanced energy & industrial efficiency technologies, such as batteries and advanced nuclear technologies*
10	*Advanced materials science, including composites 2D materials, other next-generation materials, & related manufacturing technologies.*

(Further details on the scope of the 10 key technology focus areas can be found in Appendix A.)

In the coming three-year window, TIP will focus on cultivating targeted investments to increase U.S. competitiveness in four primary key technology areas:

Artificial intelligence (AI), machine learning, autonomy, & related advances
Biotechnology, medical technology, genomics, & synthetic biology
Advanced communications technology & immersive technology
Data storage, data management, distributed ledger technologies, & cybersecurity, including biometrics

To arrive at these four primary near-term focus areas, TIP leveraged a macro-risk analysis to identify key technology areas that most urgently require acceleration to enhance U.S. competitiveness and integrated that assessment with an identification of the opportunities or vulnerabilities that the TIP directorate's use-inspired and translational research and development funding mechanisms would be best positioned to address.

The four near-term TIP focus areas will drive the development of new use-inspired and translational funding opportunities, infrastructure investments, and workforce development efforts to address key vulnerabilities to U.S. competitiveness. In tandem with these specific technology development and translation investments, many of the TIP directorate's programs will largely remain technology-agnostic, welcoming proposals spanning the full breadth of key technology focus areas.

TIP also plans to address the five societal, national, and geostrategic challenges set out by the "CHIPS and Science Act of 2022" through both the structure of the directorate's programs and dedicated investments focused on cultivating the intersections among key technology areas and the challenges. For example, all of the TIP directorate's programs will focus on strengthening national security. TIP investments will strive to advance U.S. competitiveness in the key technology areas that will define the nation's future economic and national security. TIP will also integrate elements focused on talent and workforce development across the directorate's technology and regional innovation investments.

In addition to integrating challenge areas into the design, structure, and implementation of its programs, TIP will also pursue targeted investments at the intersection of the key technology areas and the societal, national, and geostrategic challenges. Additionally, TIP investments will be structured to complement the activities of other federal agencies and leverage the directorate's unique mandate and nationwide reach. The directorate has identified areas of opportunity for impactful investments at the intersection of the key technology areas and the challenge areas of environmental sustainability and manufacturing and industrial productivity, given the multiple technologies – such as AI, high performance computing, robotics, advanced materials, and advanced energy – that could potentially help to drive game-changing solutions in both challenge areas.

Societal, National, and Geostrategic Challenges outlined in the CHIPS and Science Act of 2022

1	*United States national security.*
2	*United States manufacturing and industrial productivity.*
3	*United States workforce development and skills gaps.*
4	*Climate change and environmental sustainability.*
5	*Inequitable access to education, opportunity, or other services.*

In making technology investments and pursuant to section 1746 of the "National Defense Authorization Act for Fiscal Year 2020," section 223 of the "William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021," and the requirements under the "CHIPS and Science Act of 2022," TIP will implement research security measures in coordination with NSF-wide and federal government-wide initiatives being led by NSF's Office of the Chief of Research Security Strategy and Policy.

Guided by this roadmap, TIP will strive to make demonstrable progress toward advancing U.S. competitiveness in key technology focus areas and addressing societal, national, and geostrategic challenges, while maintaining flexibility to make investments that are responsive to emerging requirements in a dynamic technological and geopolitical landscape. Assessments of the key technology areas will be conducted every three years through the process of updating the TIP Roadmap, informing the directorate's plans for staging investments for maximal effect on U.S. competitiveness.

A Roadmap for the U.S. National Science Foundation's Directorate for Technology, Innovation and Partnerships

In today's world, technology serves as the bedrock of national competitiveness. It fuels economic prosperity, bolsters security, and empowers citizens to lead healthier, more fulfilling lives. The global technology landscape is increasingly competitive, and the pace of innovation continues to accelerate. To retain a leadership position, the United States must not only maintain pace, but also leapfrog ahead, requiring new strategies for fostering innovation and impact.

Congress recognized this when, in the "CHIPS and Science Act of 2022," it established within the U.S. National Science Foundation (NSF) the Directorate for Technology, Innovation and Partnerships (TIP) to "advance research and development, technology development, and related solutions to address United States societal, national, and geostrategic challenges, for the benefit of all Americans." The legislation further specified that the directorate should:

Support use-inspired and translational research and accelerate the development and use of federally funded research;
Strengthen United States competitiveness by accelerating the development of key technologies; and
Grow the domestic workforce in key technology focus areas and expand the participation of United States students and researchers in areas of societal, national, and geostrategic importance, at all levels of education.

TIP is focused on meeting this mandate through investments and partnerships that create diverse innovation ecosystems, drive technology translation and development, and accelerate workforce development. Building on NSF's longstanding leadership in science and engineering research and education, TIP serves as a crosscutting platform for the agency, leveraging, energizing, and rapidly advancing use-inspired research and innovation in all fields of science and engineering. These investments will help give rise to new industries and engage all Americans — regardless of background or location — in the pursuit of new, well-paying jobs. In line with its strategic vision, TIP will pursue intentional partnership with other federal agencies, industry, academia, non-profits, philanthropies, investors, and state, local, and tribal governments to inform, amplify, and scale its investments.

Pursuant to section 10399 of the "CHIPS and Science Act of 2022," this roadmap sets out the strategic vision for the TIP directorate that will guide its initial investment decisions, and details how the directorate will increase funding for research and education for populations and geographic areas underrepresented in science, technology, engineering, and mathematics and protect federally funded science and technology. Development of the roadmap was informed by: existing national strategies and guidance in each of the key technology focus areas and societal, national, and geostrategic challenge areas enumerated in section 10387 of the "CHIPS and Science Act of 2022" (enumerated below); feedback from the public in response to a request for information; analysis of open source data and investment trends; and consultations with subject matter experts. The roadmap will be updated – in consultation with relevant federal counterparts – every three years.

Guided by this roadmap, TIP will strive to make demonstrable progress toward advancing U.S. competitiveness in key technology focus areas and addressing societal, national, and geostrategic challenges, while maintaining flexibility to make investments that are responsive to emerging requirements in a dynamic technological and geopolitical landscape.

Investment approach

Strategic Framework

To accomplish its mission and mandate, TIP will structure each of its investments to advance one or more of the following core objectives:

Cultivate diverse innovation ecosystems throughout the U.S. to advance use-inspired research and innovation in key technologies and to address societal and economic challenges;

Advance U.S. competitiveness in critical and emerging technologies by developing and translating innovations and addressing national challenges; and

Grow a diverse and inclusive next-generation talent base and workforce around key technology and challenge areas, building expertise in necessary technical skills, use-inspired research and innovation, entrepreneurship, and translation.

Each investment will be evaluated through a set of common measures, assessing its ability to drive progress toward the TIP directorate's strategic goals and testing the validity of the hypothesis underpinning the structure and focus of the initiative. Logic models will be used as a component of the program design process for each TIP investment, ensuring that the desired impacts for each investment are well-defined and measurable. Results of regular assessments and evaluations will enable TIP to make early and informed decisions around sunsetting, scaling, or adjusting investments. See Appendix B for more details on the TIP directorate's approach to metrics.

Mechanisms

TIP will leverage a wide range of funding mechanisms to meet its strategic goals. Mechanisms will be customized to opportunities, tailored to meet gaps in the innovation environment or address areas of highest priority and likeliest return on investment. In some cases, TIP will rely on direct research funding focused on use-inspired and translational research. In other cases, TIP will stand up testing and prototyping environments that can facilitate researchers' ability to mature and scale new technologies, launch prize challenges that can crowdsource new ideas or solutions to specific problems, cultivate regional innovation ecosystems through large-scale investments, or support workforce development through fellowship and training opportunities, including experiential learning opportunities.

A design principle across the TIP directorate's portfolio will be a focus on the participation in the directorate's investments of Americans from a broad range of backgrounds and locations. Programs will be structured with an eye to expanding participation from communities, regions, and organizations that have not traditionally interacted with NSF and will include workforce and training elements that can help activate the full potential of the U.S. workforce.

TIP will build on and expand NSF's established Lab-to-Market Platform, which provides a range of pathways for researchers, startups, small businesses and aspiring entrepreneurs to move their ideas from the lab to society. This suite of programs includes Partnerships for Innovation, NSF Innovation Corps (I-Corps™), and America's Seed Fund powered by NSF (NSF's Small Business Innovation Research/Small Business Technology Transfer programs). In addition, TIP has initiated pilot approaches to fill gaps in lab-to-market pathways [See Figure 2]. The directorate has also initiated programs that enable new pathways for translating research results to society, including to new open-source ecosystems, government services and at-scale educational innovations.

Adopting a dynamic approach based in iterative experimentation, TIP will continue to make pilot investments to rapidly test mechanisms and then transition and scale to more significant investments and programs based on initial results. See Figure 2 for a summary of the pilots initiated in the TIP directorate's first two years of operation.

NSF has traditionally issued financial assistance awards to carry out a public purpose through grants and cooperative agreements. In addition to these mechanisms, TIP will leverage contracts as well as "other transaction authority" provided by the "CHIPS and Science Act of 2022" to support innovative approaches to fund programs managed by the directorate.

TIP will continue to seek out partners with shared values and research and development (R&D) interests with whom to co-invest and collaborate across these approaches, working closely with other directorates and offices of NSF, federal agencies, industry, academia, non-profits, philanthropic organizations, international partners, and state, local, and tribal governments. TIP investments will be structured to complement the activities of other federal agencies and leverage the directorate's unique mandate and nationwide reach. Such co-investment can take a range of forms, from in-kind contributions of resources from third parties to structures where partner investments may exceed seed funds provided by TIP. A full summary of programs supported by TIP in its first year can be found at https://new.nsf.gov/tip/about-tip

Figure 2. *TIP Directorate Pilots: A Science Of Science Approach*

Entrepreneurial Training Pilot Before and After I-Corps: *Training and mentoring for academic researchers that builds on and extends NSF I-Corps to help researchers launch a start up.*
NobleReach Emerge Pilot: *Accelerating the transition of NSF-funded research into biotech and bio-inspired designs through connections with commercialization advisors to support researchers in moving toward commercialization and translation for societal impact.*
NextCorps Pilot: *Enhancing success of startups through the provision of novel curriculum and support methodologies, including techno-economics training.*
Compass Pilot: *Supporting increased involvement and success of entrepreneurs from historically underrepresented groups to bring their innovations to the public.*
Industries of Ideas: *Developing approaches to assess the impact of NSF investments on regional firms and job in key technology focus areas.*
National Network for Critical Technology Assessment: *A network of universities completed a yearlong pilot effort with the release of a report Securing America's Future: A Framework for Critical Technology Assessment. The findings of this initial work set the foundations for the Assessing and Predicting Technology Outcomes.(Completed)*
CASE STUDY: *The National Network for Critical Technology Assessment (NNCTA) acknowledged data and analytics play a vital role in meaningfully informing national technology strategy. The report recommended the United States invest in a rapid critical technology assessment entity to provide the executive and legislative branches with the tools needed to inform national technology strategy. NSF TIP's NNCTA Pilot enabled the first step of assembling top academics from across the nation to define a vision for a critical technology assessment and validated the creation of APTO. APTO, directly informed by the NNCTA, will support a cohort of projects to create technology outcome models for the nation that will ultimately help assess and evaluate the effectiveness of U.S. R&D investments and help policymakers and decision makers optimize those investments*

Advancing key technology focus areas to strengthen American competitiveness

The “CHIPS and Science Act of 2022” set forth an initial list of 10 key technology focus areas for TIP to address through its investments (see Figure 2). NSF assessed that these areas remain critically important to U.S. economic and national security and elected to maintain the 10 areas listed in the legislation to guide the TIP directorate’s initial investments. This conclusion was informed by public feedback received in response to a request for information and made in consultation with interagency counterparts and the National Science Board.

In aggregate, the 10 key technology focus areas represent foundational drivers for the United States’ future economic growth, leadership on the global stage, and national security capabilities. Across the technology areas, there exist multiple areas of convergence and interdependence. For example, artificial intelligence (AI) holds the potential to accelerate the pace of discovery in areas such as biotechnology, semiconductors, advanced energy, and advanced materials and will be a critical driver in both capabilities of and requirements for next-generation communications technology. In addition, progress in areas such as high-performance computing and semiconductors are needed to support continued advancements in AI technologies, and AI in turn has a role in optimizing the semiconductor design and manufacturing process. These areas of convergence and interdependence will be taken into account when pursuing TIP technology investments. (Further details on the scope of the key technology areas can be found in Appendix A.)

The key technology areas also represent areas of science and engineering that have long been supported by NSF. NSF investments in fundamental research have laid the foundation for the advancements the nation is benefiting from today in each of the key technology focus areas. As such, TIP will look for opportunities to build on existing NSF investments, accelerating translation of breakthroughs supported by NSF’s investments in basic research into impactful innovations, including usable and commercially viable technologies.

Figure 1. *Key Technology Focus Areas*

1	*AI, machine learning, autonomy, & related advances*
2	*High performance computing, semiconductors, & advanced computer hardware and software*
3	*Quantum information science & technology*
4	*Robotics, automation, & advanced manufacturing*
5	*Natural & anthropogenic disaster prevention or mitigation*
6	*Advanced communications technology & immersive technology*
7	*Biotechnology, medical technology, genomics, & synthetic biology*
8	*Data storage, data management, distributed ledger technologies, & cybersecurity, including biometrics*
9	*Advanced energy & industrial efficiency technologies, such as batteries and advanced nuclear technologies*
10	*Advanced materials science, including composites 2D materials, other next-generation materials, & related manufacturing technologies.*

(Further details on the scope of the 10 key technology focus areas can be found in Appendix A.)

Sequencing TIP investments

The TIP Roadmap sets out a framework for the directorate to effectively leverage available resources by staging investments in the key technology areas for optimal effects on U.S. competitiveness. As such, in the coming three-year window, TIP will focus on cultivating targeted investments to increase U.S. competitiveness in four primary key technology focus areas: AI, machine learning, autonomy, and related advances; biotechnology, medical technology, genomics, and synthetic biology; advanced communications technology and immersive technology; and data storage, data management, distributed ledger technologies, and cybersecurity, including biometrics.

These near-term focus areas will drive the development of new use-inspired and translational funding opportunities, infrastructure investments, partnerships, and workforce development efforts to address vulnerabilities to U.S. competitiveness that TIP has identified over the next three years. In tandem with these specific technology development and translation investments, many of the directorate's programs – such as the NSF I-Corps, Partnerships for Innovation, and America's Seed Fund powered by NSF – will largely remain technology-agnostic, welcoming proposals spanning the full breadth of key technology areas. As TIP moves forward, it will explore opportunities to scale investments into other key technology focus areas, contingent on availability of funds. In some cases, TIP may initiate a new investment, and in others, it may co-invest with existing NSF programs. Assessments of the key technology areas to inform how to stage investments for maximal effect on U.S. competitiveness will be conducted every three years through the process of updating the TIP Roadmap.

TIP arrived at the four primary areas for near-term technology investments through the development of an analytical framework that analyzed each of the key technology areas in the context of nine dimensions of competitiveness (see Table 1) to assess risks for U.S. competitiveness and determine urgency of investments. At each intersection point, TIP identified key vulnerabilities, modes, timelines, and conditions that contribute to U.S. competitiveness and the risks assessed. TIP then paired this assessment with the identification of high-impact opportunities for TIP investments that would address these risks and vulnerabilities and would meet one or more of the directorate's core objectives. Such opportunities were informed by awareness of other federal agency priorities and areas of investment, seeking to identify the opportunities aligned with the TIP directorate's mandate and investment mechanisms. Dimensions of the framework implicitly took account of the relative time urgency associated with risk and investment opportunities, as well as dependencies across the key technology areas.

To derive the four primary near-term technology focus areas, TIP leveraged the macro-risk analysis to identify key technology areas that most urgently require acceleration in order to enhance U.S. competitiveness and integrated that assessment with an identification of the opportunities or vulnerabilities that the TIP directorate's use-inspired and translational R&D funding mechanisms would be best positioned to address. In bringing together these elements, TIP considered the urgency of investments and the activities and levels of investment of other federal agencies –including from the CHIPS and Science Act of 2022 toward building domestic semiconductor capacity and investments through both the Infrastructure Investment and Jobs Act and the Inflation Reduction Act of 2022 in clean energy – to determine the directorate's near-term focus areas. TIP partnered with The MITRE Corporation, a non-profit research organization, to conduct this analysis through an existing Federally Funded Research and Development Center (FFRDC) contract. MITRE leveraged the more than 200 public responses to a request for information released in April 2023, national policy documents, and external studies to reach conclusions. The vulnerabilities and opportunities identified in the four primary focus areas are explored in more detail below.

Table 1: *Risk Analysis Framework*

Dimension of Competitiveness	**Risks Analyzed** (using a five-year outlook)
Market strength/market size	*Risks associated with the overall size of the potential market within the next five years that can be served by the key technology focus area, and the level of certainty that the potential market will materialize.*
Market strength/capital flows	*Risks associated with the availability of capital needed to move the key technology focus area from its current state to production at scale, including total investment required, availability of willing investors, availability of associated financial and insurance products, and the speed and magnitude of capital flow.*
Workforce talent and skills	*Risks associated with the human capital and capabilities required to educate, design, produce, install, maintain, and operate products in the key technology focus area at scale.*
Workforce equity and opportunity	*Risks associated with the diversity of human capital and their equitable access to human capital systems, including performance, recognition, education, and training needed to design, produce, maintain, and operate products in the key technology focus area at scale.*

Table 1: *Risk Analysis Framework continued*

Dimension of Competitiveness	**Risks Analyzed** (using a five-year outlook)
Supply chain and manufacturing	*Risks associated with moving an innovation into the market and society, e.g., via manufacturing at scale, including existing domestic manufacturing capacity, the necessary industrial capacity to support the manufacturing base, the maturity of the supply chain, and the technology, equipment and other intellectual property and licensing needed to support production and/or service provisioning at scale.*
Infrastructure for translational research	*Risks associated with the physical and digital at-scale systems and environments that need to be in place to support, enable, or facilitate development, translation, and deployment at scale into society (e.g., collaboration environments, testbeds, networks, and data repositories).*
Governance/regulatory environment	*Risks associated with local, state, and federal regulations or other requirements or standards evolving that must be met to deploy the key technology focus area products at scale.*
American leadership	*Risk associated with the U.S. not attaining, or not maintaining, a leading position of strength and influence in the global marketplace in the face of serious international techno-economic competition.*
National security	*Risks associated with not realizing the strategic benefits the key technology focus area presents for achieving critical capabilities and advantages necessary to achieve national security priorities.*

AI, machine learning, autonomy, and related advances

AI and machine learning have emerged as transformative forces shaping our present and future, holding the potential to power solutions to global challenges; revolutionize how we work, learn and play; unlock scientific breakthroughs; and shape the balance of power on the world stage. Unlocking this potential in the United States requires investments across the AI innovation ecosystem, particularly to address vulnerabilities to U.S. competitiveness related to building an AI workforce with pathways available and accessible to all communities, strengthening supply chains, expanding access to necessary research infrastructure, accelerating the application of AI, and increasing trustworthiness of AI systems.

TIP will explore such opportunities to identify impactful investments to increase U.S. competitiveness in AI. The directorate will also strive to identify the ways in which TIP investments can spur innovation in the use of AI to drive progress and discovery in the other key technology focus areas.

Potential TIP investments to address these opportunities and vulnerabilities include:
Making targeted investments in applications of AI in specific fields, such as biotechnology, advanced materials, and advanced manufacturing, to accelerate the development of effective solutions and spur economic competitiveness. These investments would lay the foundation for increased adoption of AI solutions across sectors.
Facilitating the curation of high-quality datasets suited to the training of AI models that are tailored to specific domains or tied to societal, national, and geostrategic challenges. Such efforts, particularly if made available through common data environments, such as the National AI Research Resource pilot, would enable the development of responsible AI solutions in areas of high impact.
Supporting the creation of testbeds for the research and innovation community to prototype and test AI-based solutions in a range of real-world scenarios, helping to accelerate the translation of innovations into practice and encouraging robust safety evaluations. Such assets can also serve the R&D community by facilitating access to curated and specialized datasets for testing and benchmarking.
Advancing responsible AI systems development and deployment by supporting multisector collaborations to advance methodologies for building safety, trust, transparency, and accountability into AI systems in the context of practical use cases.
Developing inclusive pathways for increased workforce development opportunities through community colleges, reskilling programs, and experiential learning opportunities that emphasize data science skills and/or integrate the use of AI, machine learning, and data science within the context of traditional programs alongside instruction in responsible and ethical AI.

Advanced communications technology and immersive technology

Information powers the economy, underpins collaboration, and stimulates innovation. Advances in communication and immersive technology hold the potential to supercharge the flow of information, transforming the ability to collaborate, fueling real-time decision-making, and accelerating the ability to unlock economic potential. Furthering advanced communication capabilities in the United States is also critical to many other key technology focus areas. In particular, there is an opportunity for the United States to lead in the development and adoption of edge/near-edge computing, dynamic spectrum sharing, immersive technologies and low Earth orbit satellite (LEOS) communication that will revitalize the sector, increase access to services and have positive consumer, industrial, societal and national security implications. Advanced cloud technologies can enable computing at and near the edges of a network, facilitating new applications of combined sensing, prediction, and automated decision making. These and other capabilities are also enabling new approaches to augmented, virtual, mixed, and extended reality with numerous use cases in areas such as industrial automation, education, entertainment and telemedicine.

At the same time, the TIP directorate is cognizant of U.S. vulnerabilities in this space. In recent years, the United States has excelled at basic research but has trailed behind global peers in the commercialization and manufacturing of key components of cellular radio systems and in the integration of mobile networks as outlined in a 2022 report by the Special Competitive Studies Project (SCSP) on U.S.–China technology competition. For example, per SCSP's report, in 5G technology specifically, People's Republic of China (PRC)-backed companies were rapidly becoming the market standard for network hardware for swaths of the global internet. In fact, the U.S. had little or no market-ready alternatives and only a U.S. diplomatic intervention slowed China's expansion and subsequent dominance of the 5G market. Strengthening the U.S. position on advanced communications and immersive technologies requires efforts to strengthen domestic capabilities in specific areas, and may also require steps to address supply chain vulnerabilities, make testing infrastructure more accessible, and address workforce shortages.

TIP will explore investments along these lines to increase U.S. competitiveness in advanced communications and immersive technologies, seeking opportunities to accelerate the translation of research into game-changing commercial innovation and focusing on areas that can secure U.S. leadership by leapfrogging competitors and/or re-shaping the competitive landscape to leverage U.S. strengths in adjacent technologies.

Potential TIP investments to address these opportunities and vulnerabilities include:
Spurring a reimagination of the internet's access network and how it is used by leveraging U.S. strengths in cloud and edge devices to enable low-latency and immersive applications.
Extending the U.S. lead in spectrum-related technologies – such as dynamic spectrum sharing and software-defined radio – to cost-effectively use higher frequency radio bands.
Building on U.S. leadership in high-bandwidth/low-latency LEOS communication, with emphasis on increased access to services; novel applications, some of which may be global in scope; and the dynamic combination of LEOS and terrestrial capabilities.
Investing in translational research and development to revitalize the local wired/fibered infrastructure that services most U.S. homes and businesses and provides the backhaul/fronthaul capabilities that the mobile network depends on.
Supporting testbeds and access to customer and government testing environments for advanced communication and immersive technologies to enable innovators to test, refine, and demonstrate their innovations in real-world conditions and accelerate adoption by commercial and government customers.
Expanding fellowship, traineeship, and apprenticeship programs to create more pathways to technical careers in the advanced communications and immersive technologies industry, with particular focus on broadening participation within the workforce.

Biotechnology, medical technology, genomics, and synthetic biology

The convergence of biology, chemistry, materials, engineering, and computer science has given rise to biotechnology's potential to reshape sectors from agriculture to pharmaceuticals. From engineering insulin-producing bacteria to bioremediating polluted soil, biotechnology holds the potential to offer solutions to challenges in healthcare, sustainability, food production, and beyond. Increasing global competition and concerns related to biosafety and biosecurity make sustaining U.S. leadership a priority with respect to economic competitiveness and national security. Realizing the transformative possibilities of biotechnology across application areas and in the service of national security requires longer-term investments, improved manufacturing capabilities, expanded infrastructure that supports the translation of research, and the development of the U.S. talent base.

TIP will explore such opportunities to make investments aimed at increasing U.S. competitiveness in biotechnology. The directorate's investments related to this technology area will include considerations of and requirements for biosafety and biosecurity.

Potential TIP investments to address these opportunities and vulnerabilities include:
Accelerating use-inspired research translation focused on applications of biotechnology, genomics, and synthetic biology that extend beyond human therapeutics into areas such as advanced manufacturing, environmental sustainability/remediation, agriculture, and climate resilience.
Supporting access to instrumentation and prototyping facilities to aid in the translation of ideas from the lab into products with commercial potential.
Expanding workforce development opportunities, with an emphasis on opportunities at community and technical colleges.
Partnering with industry to develop technical and process innovations – especially those that leverage AI – to increase the speed, reliability, and efficiency of biomanufacturing.
Creating lab-scale environments and software-based models that accurately mimic large-scale manufacturing to facilitate identification and remediation of scaling challenges earlier in the R&D cycle.
Building innovation ecosystems in specific areas – such as protein design, enzymes, molecular recognition, cell-free technology – that hold the potential to lead to new industries, particularly when leveraging advanced AI and machine learning approaches.

Data storage, data management, distributed ledger technologies, and cybersecurity, including biometrics

Rapid technological innovations are allowing for the generation, collection, sharing, analysis, and seamless flow of large amounts of data. These advances, in conjunction with the rapid adoption of AI, provide unprecedented opportunities to derive value from the accumulated data to support evidence-based decision-making capabilities; accelerate scientific discovery and innovation, including the further acceleration of AI; and reap immense social and economic benefits. However, harnessing this data to unlock such potential demands secure and efficient storage solutions, robust cybersecurity, and trusted methods for secure and private data sharing and record keeping. These requirements become more critical when considering biometric data and how to responsibly leverage biometric approaches for authentication and personalization.

Moving toward a future where the power of data is effectively and securely harnessed and the U.S. maintains a lead in the trustworthy development, commercialization, and application of leading-edge data-related technologies will require a series of investments. These include efforts to develop the necessary workforce, improve design and manufacturing capabilities to enable new data storage technologies, fully integrate advanced biometric capabilities to protect sensitive data, develop cybersecurity test-range technologies and datasets to build and test the defenses used by U.S. companies and government agencies to protect sensitive data, advance anti-tamper solutions for data storage, and pursue the development and application of privacy-enhancing technologies. Actions to develop new cybersecurity capabilities and address vulnerabilities, especially in critical infrastructure, will also be required.

TIP will explore such opportunities to make investments aimed at increasing U.S. competitiveness in data storage, data management, distributed ledger technologies, cybersecurity, and biometrics. The initial focus will center on areas related to data management and privacy-enhancing technologies. During this initial three-year period, the TIP directorate will assess the opportunities and vulnerabilities associated with the data storage industry’s technology roadmap, including its advanced materials and advanced manufacturing requirements.

Potential TIP investments to address these opportunities and vulnerabilities include:
Incentivize creative uses of data management technologies, especially privacy-enhancing technologies, through mechanisms such as prize challenges and bug bounties to identify and develop solutions to vulnerabilities in data storage or biometrics applications.
Fostering national and regional efforts to build capacity, especially workforce capacity, for data storage and biometrics device manufacturing.
Supporting the creation of sandbox testing and experimentation environments for privacy-enhancing, distributed ledger, and cybersecurity technologies to stress-test approaches, diagnose and address vulnerabilities, build trust, and facilitate inter-operation and/or standardization.
Encouraging the development of open-source tools and datasets that can help organizations implement and test privacy-enhancing technologies and cybersecurity capabilities
Fostering use-inspired R&D to advance the application of innovative models, methodologies, or constructs to mature and scale the integration of privacy-enhancing technologies into systems-level solutions that are user friendly and trustworthy.
Broadening the scope of digital ledger technology applications such as smart contract capabilities to enable their use within traditional financial environments and the creation of trustworthy digital assets and/or new value exchange mechanisms.

Addressing societal, national, and geostrategic challenges

The "CHIPS and Science Act of 2022" sets out five societal, national, and geostrategic challenges to guide the character and strategic focus of the TIP directorate's investments:

U.S. national security;
U.S. manufacturing and industrial productivity;
U.S. workforce development and skills gaps;
Climate change and environmental sustainability; and
Inequitable access to education, opportunity, or other services.

Some of these challenges will be addressed through dedicated investments focused on cultivating the intersections of key technology focus areas and challenges, while others will be addressed across the TIP directorate's investments through the structure and intended outcomes of those investments and partnerships with other federal agencies.

Universal to TIP programs is a focus on strengthening national security. TIP investments will strive to advance U.S. competitiveness in the key technology areas that will define the nation's future economic and national security. TIP is also expanding its collaboration with defense and intelligence partners such as the Office of the Director of National Intelligence and U.S. Africa Command to make joint investments in technology areas of high shared priority, maximizing the ability to accelerate development. TIP investments will be uniquely formulated to accelerate the translation of research into practice and meet demonstrated structural challenges in the U.S. national innovation ecosystem. This innovation ecosystem remains critical to sustaining national security through both economic growth and the development of capabilities that provide the U.S. defense and intelligence communities technological advantages.

Similarly, in addition to workforce-specific investments such as the new Experiential Learning for Emerging Novel Technologies (ExLENT) program, TIP will integrate elements focused on talent and workforce development across the directorate's technology and regional innovation investments. For example, each of the NSF Regional Innovation Engines (NSF Engines) will be required to carry out regional workforce development activities to build the scientific and technical workforce in its region of focus. In addition, programs and outreach about TIP opportunities will strive to engage and bring in new awardees from underrepresented regions, communities, and organizations, as well as non-traditional recipients of NSF awards. For example, concerted outreach efforts for the NSF Engines program resulted in a slate of awardees for NSF Engines Development Awards, including 27% that were first-time NSF awardees, 39% that were from Established Program to Stimulate Competitive Research (EPSCoR) jurisdictions,[1] 25% that were non-academic institutions, and 16% that were minority-serving institutions.[2] This core approach will be complemented by focused efforts to overcome inequitable access by building capacity in underrepresented communities and institutions to participate and benefit from the directorate's investments, such as through the Enabling Partnerships to Increase Innovation Capacity (EPIIC) program, which will build the capacity of minority serving institutions, primarily undergraduate institutions and two-year institutions to participate as partners in future NSF Engines.

In addition to integrating challenge areas into the design, structure, and implementation of its programs, TIP will also pursue targeted investments at the intersection of key technology focus areas and societal, national, and geostrategic challenges. Areas of opportunity for impactful investments have been identified at the intersection of key technology focus areas and the challenge areas of environmental sustainability and manufacturing and industrial productivity, given the multiple technologies such as AI, high performance computing, robotics, advanced materials, and advanced energy that hold the potential to help drive game-changing solutions.

The NSF Engines program exemplifies investments that strive to meet all three of TIP's strategic objectives by cultivating innovation ecosystems, accelerating technology translation, and developing the next-generation workforce. It also illustrates where TIP has already taken significant steps to invest in cultivating technology development in the context of societal challenges. Announced in January 2024, the inaugural NSF Engines awards established 10 NSF Engines across the country, supporting the cultivation of regional-level innovation ecosystems through market-driven research and development, technology translation, and workforce development. Each NSF Engine will tackle a societal challenge through technology development, advancing new solutions and expanding job opportunities in the process.

For example, the NSF Southwest Sustainability Innovation Engine based in Arizona, Nevada and Utah seeks to transform water security, renewable energy, and net carbon emissions in the region by incentivizing new technology and expanding infrastructure and capacity. The NSF North Dakota Advanced Agriculture Technology Engine aims to create resilient and secure food systems in North Dakota by combining advanced genomics, climate modeling, nanoscale sensors, and computer networks to monitor and improve the growth of crops. The NSF Central Florida Semiconductor Innovation Engine aims to play a critical role in bolstering the nation's capability for semiconductor advanced packaging design and manufacturing.

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1 The U.S. National Science Foundation's EPSCoR program pursues a mission to enhance the research competitiveness of targeted jurisdictions (state, territory or commonwealth) by strengthening science, technology, engineering and mathematics (STEM) capacity and capability through a diverse portfolio of investments from talent development to local infrastructure.

2 https://tableau.external.nsf.gov/views/EnginesType-1AwardAnnouncement/Demography?%3Aembed=y&%3AisGuestRedirectFromVizportal=y

Ensuring the security of TIP investments

In making technology investments and pursuant to section 1746 of the National Defense Authorization Act for Fiscal Year 2020, section 223 of the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021, and the requirements under the CHIPS and Science Act of 2022, TIP will implement research security measures in coordination with NSF-wide and federal government-wide initiatives being led by NSF's Office of the Chief of Research Security Strategy and Policy. These measures include the requirement across all TIP funding opportunities of comprehensive disclosure of current and pending research support, in accordance with the harmonized federal disclosure requirements. [3]

In addition, TIP has pursued additional research security requirements for the directorate's significant investments, such as the requirement for each NSF Engine to designate a member of the NSF Engine's leadership team as the research security point of contact with responsibility for research security oversight of the NSF Engine's activities, research results, and shared resources in accordance with National Security Presidential Memorandum - 33 (NSPM-33) and its implementation guidance.

As TIP pursues investments in critical technology areas, including those that strive to advance open-source resources, the directorate will coordinate closely with NSF's Office of the Chief of Research Security Strategy and Policy to continue implementing research security best practices across its programs and build the capacity of the research community to mitigate risks from foreign interference. Such efforts will particularly benefit from the recent actions of the Office of the Chief of Research Security Strategy and Policy to build a clearinghouse to empower the research community to identify and mitigate foreign interference, improve the quantitative understanding of the scale and scope of research security risks, develop research security training modules for researchers and institutions across the U.S., implement foreign financial disclosure requirements above and beyond requirements outlined in the NSPM-33 Implementation Guidance, and create tools to identify potential foreign interference between NSF-funded researchers and researchers abroad.

Through its Office of the Chief of Research Security Strategy and Policy, NSF plays an active role in federal interagency coordination to advance government-wide research security and serves as co-chair of the National Science and Technology Council's Subcommittee on Research Security. The Office of the Chief of Research Security Strategy and Policy's mission to identify risks to the U.S. research enterprise and develop research security policy and best practices remains critical to NSF's goal of promoting continued U.S. leadership in science and engineering and furthering the TIP directorate's mandate to increase U.S. competitiveness in key technology efforts. Going forward, TIP will maintain its close partnership with the Office of the Chief of Research Security Strategy and Policy to embrace best practices, take proactive measures to secure its science and technology investments, and pilot new risk identification and mitigation processes.

3 https://www.nsf.gov/bfa/dias/policy/nstc_disclosure.jsp

Conclusion

This roadmap will serve to set the strategic vision for the directorate for the next five years and guide programmatic investments over the course of the next three years. The TIP directorate will collect metrics from each of its investments to measure success and impact and incorporate evaluation as a critical element from the outset of each investment. As the directorate's programs mature, metrics will provide feedback into the next iteration of the TIP Roadmap to inform future investments, priorities, and program designs.

Appendix A:
Key Technology Focus Areas

Each key technology focus area defined in the “CHIPS and Science Act of 2022” represents a critical driver for U.S. competitiveness and encompasses a diverse range of technical sub-topics and areas of interest for use-inspired and translational research. For each key technology focus area, TIP has defined a set of primary sub-topics to inform analysis of investment opportunities, as described below.

(1) AI, machine learning, autonomy, and related advances

Advances in artificial intelligence (AI), machine learning, and autonomy have begun to impact aspects of daily life and are transforming industries by enabling rapid innovation, enhancing human-computer interaction, and facilitating applications in areas such as national security, manufacturing, healthcare, logistics, and environmental sustainability. While translational research investments in AI will bring societal benefits, it is important to also conduct research that ensures responsible and safe AI application by addressing AI assurance and associated risks depending on the context of use. These factors include AI system security, equity, reliability, interpretability, robustness, privacy, and governability.

Examples of key technologies within the AI sub-topic are natural language processing, computer vision, and generative AI. Machine learning technologies include deep learning, reinforcement learning, and large language models. Together, these technological advances can translate into real-world applications across society, leading to improved decision-making, efficiency, productivity, and innovation—and ultimately strengthening the U.S. competitive advantages globally. Specialized computational hardware including graphics processing units that are important to support advances in this area are considered within key technology focus area #2.

Subtopics:
Artificial intelligence
Machine learning
Training data collection and curation
Autonomy

(2) High-performance computing, semiconductors, and advanced computer hardware and software

High-performance computing (HPC), semiconductors, and advanced computer hardware and software are fueling innovation across fields, supporting advancements across many of the other key technology focus areas.

HPC provides computational power orders of magnitude faster than commodity computing devices. The world's most powerful computing systems support complex workloads ranging from large language models for AI to the modeling and simulation of physical systems with applications to climate, weapons design, and manufacturing.

Continued progress in semiconductors will underpin advances in AI, HPC, cloud computing, communications and immersive technologies, and robotics and manufacturing, among other areas. Areas of interest within the sub-topic of semiconductors includes semiconductor materials, devices, and manufacturing; design of semiconductor chips; and the design automation tools that enable central processing units (CPUs), graphics processing units (GPUs), accelerators for specific functions (e.g., machine learning), memory, storage, communications and networking, displays, sensors and actuators.

At a more modular level than the chips themselves, advances in computer hardware lead to new approaches to combining, interconnecting, and packaging collections of chips into handsets, personal computers, servers, and data centers. For example, the most powerful HPC and AI systems utilize novel interconnect technologies to efficiently transfer data among the system components.

Similarly, advanced computer software orchestrates the actions of components, within individual devices, among the servers of a data center, and across distributed systems that span the globe. For example, programming languages, operating systems, middleware, parallel programming and scientific software frameworks, software engineering, and distributed systems software all fall within this area. This sub-topic also includes work on algorithms, computational complexity, and the theory of computing.

Subtopics:
High-performance computing
Semiconductors
Advanced computer hardware
Advanced computer software

(3) Quantum information science and technology

Quantum information science (QIS) is the study of how quantum phenomena can be exploited to enhance information technologies, including computation, communications, and sensing.

Certain types of quantum sensors are available and in use today for a range of applications, especially timing and scientific instrumentation. Although still in their infancy, some of the potential applications of quantum computing are molecular-scale simulations of chemical and biological systems, machine learning, approximate solutions to challenging optimization problems, simulations of large-scale economic models, and algorithms that can theoretically be used to compromise current encryption protocols. Potential applications of quantum communications include the distribution of encryption keys and the interconnection of quantum computer modules. Due to QIS's disruptive potential in cybersecurity, protected information transfer, instrumentation, timing, machine learning, simulation, and optimization, the U.S. must sustain its competitive position despite strong competition from other nations.

Subtopics:
Quantum computing algorithms and software
Quantum computing hardware
Quantum communications and networking
Quantum sensing
Quantum device components and manufacturing methods

(4) Robotics, automation, and advanced manufacturing

Robotics and automation are primary mechanisms for advancing U.S. manufacturing capabilities. In parallel to these enabling technologies, advanced manufacturing research leverages emerging technologies and processes to improve conventional manufacturing pipelines by improving cost, yield, efficiency, and precision.

The scope of robotics activities includes a wide range of autonomous vehicles together with cyber-physical systems that include networked sensors and actuators. As a sub-topic, robotics also includes the software that enables individual robots, the coordinated operation of multiple robots, and human-robot collaboration. Automation includes topics such as factory automation, robotic process automation, workflow automation, and digital twins.

Advanced manufacturing includes topics such as computer-aided product design, manufacturing plant design and process flow, supply chain logistics, industrial Internet of Things, and agile, sustainable, energy-efficient and/or precision manufacturing. Newly emerging processes, such as additive and in-space manufacturing are also considered within the context of this area. Expanded integration of advanced manufacturing practices improves U.S. competitiveness by reducing manufacturing costs, enabling the manufacturing of emerging advanced products, and reducing dependencies on foreign supply chains.

Subtopics:
Robotics
Automation
Advanced manufacturing

(5) Natural and anthropogenic disaster prevention or mitigation

The U.S. faces an increasing number of natural and anthropogenic disasters, including flash and long-term droughts, floods, severe storms, catastrophic wildfires, and extreme heat events. On an annual basis, few areas are immune to these costly cascading impacts, and these events are increasing in scale, duration, intensity, and frequency. In addition to their direct impact on the lives of our citizens, these events can have correlated and systemic impacts on the insurance and financial markets and on the supply chains of many industries.

Examples of relevant technologies include distributed early warning systems, tools to enable more effective planning of civilian infrastructure and housing, novel materials that can improve the resilience of large-scale engineering structures, stormwater and fire management technologies, and physics-based digital twin models for simulation, modeling, and visualization. To maintain U.S. competitiveness and productivity, the U.S. must protect its workforce, critical infrastructure, essential services, and supply chains from the harshest effects of natural and anthropogenic disasters.

Subtopics:
Natural disaster prevention and mitigation
Climate change adaptation and mitigation
Anthropogenic disaster prevention and mitigation
Pandemic prevention and response

(6) Advanced communications technology and immersive technology

Advanced communications and immersive technologies seek to seamlessly converge the physical, digital, and biological worlds to provide users with enhanced experiences. Accordingly, this topic includes both the communications/networking technologies themselves and the immersive technologies and edge devices that are used to access them.

Current commercial mobile network operators are deploying 5G and beginning to define 6G networks. Underlying both are advanced communications capabilities that enable new use cases such as augmented, virtual, mixed, and extended reality, in addition to new vertical use cases such as industrial automation and telemedicine. While 5G is cloud native, 6G is expected to be AI native, leveraging AI-based network and spectrum management capabilities within the communications infrastructure. The growth in traffic carried by these future networks will be driven by massive increases in the number of Internet of Things devices and the sophistication of the sensors they are equipped with.

Communications is a cross-cutting enabler for many of the other key technology focus areas and has significant national security implications. Although the United States is currently lagging with respect to important aspects of this topic, especially the commercialization of radio access nodes and the integration of wireless access networks, it continues to have significant strengths with respect to the networks that carry traffic within the cloud, the software platforms used within edge devices, spectrum sharing, and basic research.

Subtopics:
Wireless communication
Wired/fiber communication
Spectrum management
Communications and network security
Internetworking
Immersive technology and edge devices

(7) Biotechnology, medical technology, genomics, and synthetic biology

This technical area comprises applied life sciences and associated engineering activities. The medical technology sub-topic comprises a wide range of medical devices, instrumentation and software that are used for diagnostic, therapeutic and clinical purposes. The biotechnology, genomics, synthetic biology, and associated bio-manufacturing sub-topics are sometimes collectively referred to as the "bioeconomy." These technologies can drive advances in areas such as vaccine and drug discovery, gene therapies, increased and more resilient food production, and sustainable materials/manufacturing.

Factors impacting U.S. competitiveness and national security risks range from strategic dependence on adversaries for medical countermeasures, critical drugs, and food production to the proliferation and/or potential misuse of biotechnologies by state or non-state actors.

Subtopics:
Genomics and bioinformatics
Medical technology
Synthetic biology
Biotechnology
Bio-manufacturing

(8) Data storage, data management, distributed ledger technologies, and cybersecurity, including biometrics

U.S. security and competitiveness rely on information systems that securely store, compute, and manage rapidly growing amounts of data. The data storage sub-topic addresses the underlying physical mechanisms for data storage and their integration into modular storage systems at ever-increasing densities, capacities, and read/write throughputs. The data management sub-topic deals with the organization of that data into file systems and databases at a wide range of scales from single user devices to enterprise-scale systems to global-scale, cloud-based repositories that meet mission-relevant resilience and availability criteria. The decentralized ledgers sub-topic adds additional considerations related to decentralized governance, smart contracts, and non-fungible digital assets.

This topic also includes sub-topics related to cybersecurity, data privacy, and biometrics which, together, can ensure the trustworthiness of the data-driven economy. Ensuring the resilience of systems to a wide variety of cyberattacks requires an increased ability to anticipate emerging threats, incorporate security considerations into the development of new information technologies, and, when necessary, rapidly deploy countermeasures. Data privacy is a space in which there is an urgent need to incorporate research breakthroughs, such as in privacy-enhancing technologies into practical systems. Finally, with appropriate safeguards, biometrics can facilitate additional ways of authenticating human users of computer systems based on physical and/or behavioral characteristics.

The wide range of technologies in this topic is critical to enabling the continued growth of the data-driven economy. We must expand the scale at which data is curated and utilized, while also ensuring the trustworthiness of data, systems, and networks, so that individuals and organizations can safely collaborate with each other and with government agencies and protect privacy and confidentiality of data, where needed.

Subtopics:
Biometrics
Cybersecurity
Data management / databases
Data storage
Data privacy
Distributed ledger technologies

(9) Advanced energy and industrial efficiency technologies, such as batteries and advanced nuclear technologies

The technologies within this focus area will be critical to achieving the nation's sustainable energy goals and to improving energy resilience.

Key opportunities for advancing competitiveness within energy generation include the accelerated translation of research results related to a range of sustainable sources, including solar, wind, tidal, geothermal and biofuels. This sub-topic also includes technologies facilitating cost-effective hydrogen manufacturing and use. Energy storage includes innovations in the underlying storage mechanisms and in their integration with microgrids and smart grids. Advances in transmission and distribution systems may come from the incorporation of new conductive materials and transformers into the grid and/or from improved grid management using industrial Internet of Things (IoT) and cyber-physical systems (CPS). Carbon management techniques, especially those that are deployed at the points of energy generation or use, are also considered within the context of this topic. Advances in nuclear energy research and development include evaluation of small- and micro-reactor technologies and designs, as well as life-cycle monetization.

While the above sub-topics focus primarily on the supply and distribution of energy, improvement in industrial efficiency technologies that can substantially reduce energy demand also fall within this technology area. Opportunities in industrial efficiency technologies include information-based opportunities to improve efficiency through the rapid adoption of industrial IoT and CPS. They also include opportunities to improve the electrical, mechanical and/or thermal efficiency of energy consumption through cogeneration, waste heat recovery, micro-turbines, improved HVAC systems, etc.

Investments in energy-related technologies will accelerate the deployment of sustainable energy technologies and bolster U.S. national security and competitiveness through increased energy security and lower energy costs. Advancement of these technologies could also contribute to the revitalization of American manufacturing.

Subtopics:
Advanced batteries and energy storage
Advanced energy generation
Advanced transmission and distribution systems
Carbon management technologies
Advanced nuclear technologies
Industrial efficiency technologies

(10) Advanced materials science, including composites 2D materials, other next-generation materials, & related manufacturing technologies.

Materials are the building blocks of everything we manufacture. Advanced materials provide novel characteristics, such as lighter weight and/or improved strength, thermal, chemical or electrical properties. Engineers leverage new materials to realize dramatic improvements in existing technologies and to enable entirely new applications.

Composites, such as the combination of carbon fiber and resins, can be lighter and stronger than pre-existing alternatives, which makes them especially attractive for use in aerospace applications. 2D materials, which have extremely high surface to volume ratios, are well-suited to electronic, chemical-sensing and/or bio-sensing applications and can also serve as a component of composite materials. Examples of other next-generation materials of interest include metamaterials, topological materials and materials that extend the applications of additive manufacturing. This key technology area also includes related manufacturing technologies, such as improvements that can enable the clean domestic processing of critical materials and/or the substitution of alternative raw material inputs to ensure the resilience and sustainability of the advanced materials supply chain.

Advanced materials and manufacturing are critical to national security, economic competitiveness, improved quality of life, and addressing climate change. The rapid translation of scientific and technological advances in materials science and manufacturing to defense, industrial, and applied science applications is a key enabler of progress in many of the other key technology focus areas.

Subtopics:
Composites
2D materials
Other next-generation materials
Related manufacturing technologies

Appendix B:

TIP Metrics and Evaluation Approach

TIP is creating a framework of progress and impact indicators (metrics) aligned with the TIP directorate's three core objectives:

Cultivate diverse innovation ecosystems throughout the U.S. to advance use inspired research and innovation in key technologies and to address the nation's societal and economic challenges;

Advance U.S. competitiveness in critical and emerging technologies by translating innovations and addressing national challenges; and

Grow a diverse and inclusive next-generation talent base and workforce around key technology and challenge areas, building expertise in use-inspired research and innovation, entrepreneurship, and translation.

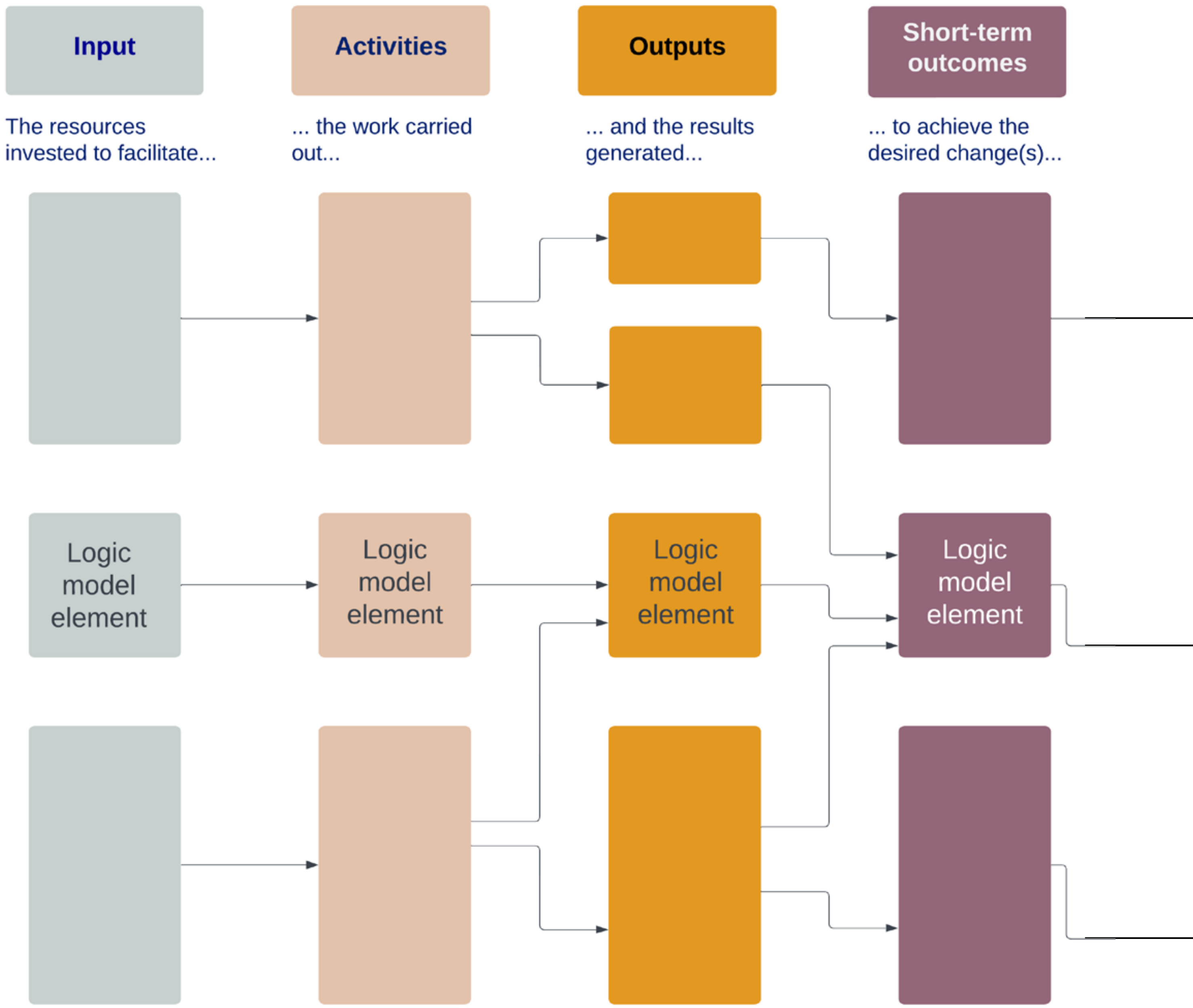
The intent of the framework is to evaluate the near-, mid- and long-term value from TIP led programs, creating a TIP dashboard that can monitor the impact of investments across programs over time to assess effectiveness and inform future investment.

For example, to assess progress towards the TIP directorate's first goal, TIP is seeking to evaluate the growth in magnitude and geographic diversity of translational activities seeded by TIP enabled innovation ecosystem, including but not limited to technology licensing, formation and ongoing success of startups, and scaling of open-source platforms. For the second goal, TIP is considering measuring advancement of research to market by quantifying the growth in non-government investment for development, commercialization and/or societal adoption of TIP funded activities. Similarly, for the third goal, TIP is considering measuring growth in training and development of workforce in key technology and challenge areas across all levels of education.

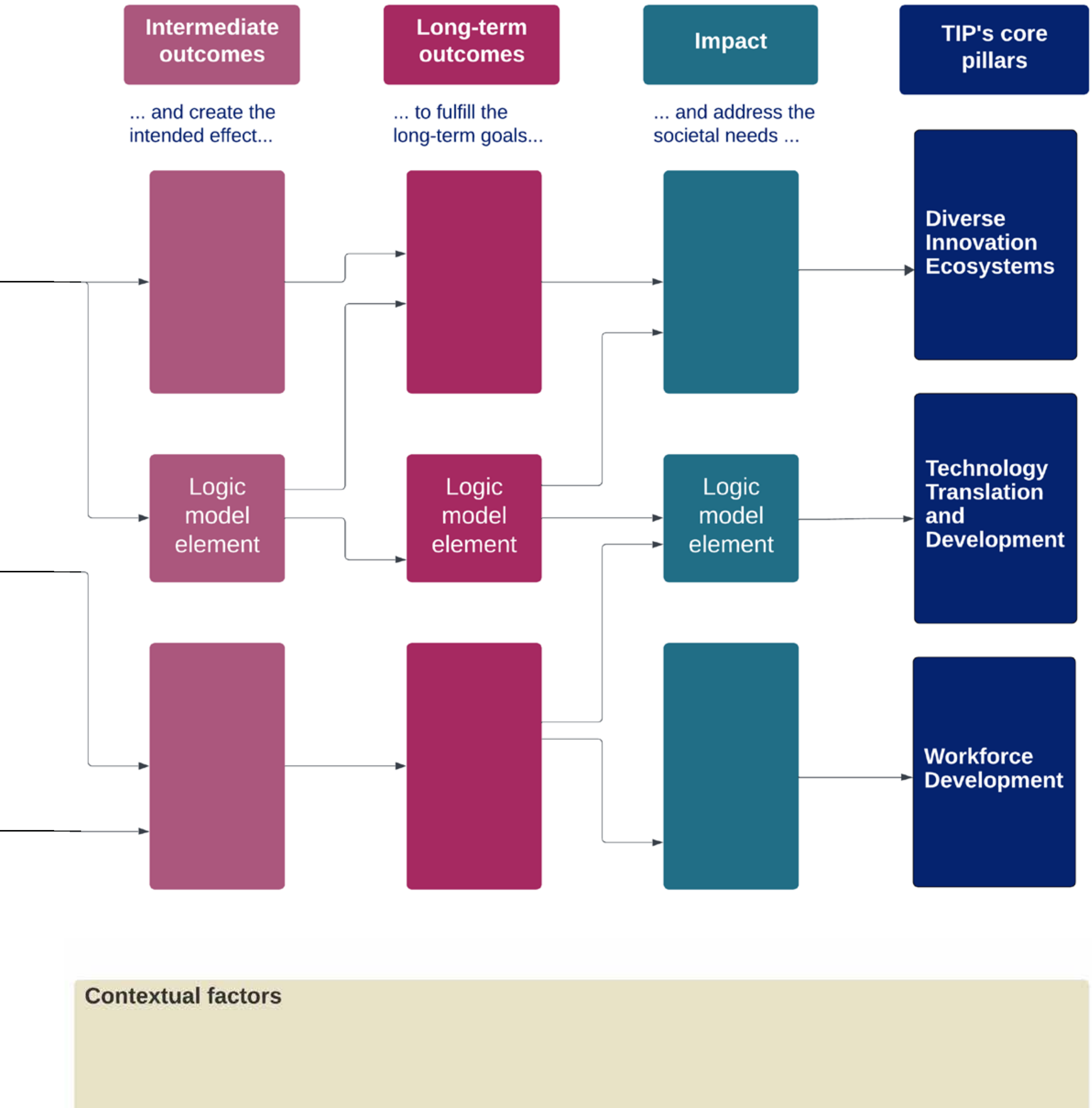
To operationalize the framework, TIP will use logic models aligned with each of its investments and programs. A logic model is a graphical depiction tool that lays out a shared understanding of what resources are available (inputs), what changes will occur (activities), what these activities will produce (outputs), and what the intended short- and long-term impacts (outcomes) of the program will be. The result of a logic model is a program's theory of change, with a roadmap of what steps need to be taken in order to produce the desired impacts. See graphic on page 38 & 39.

As each logic model is developed, elements from the logic model are identified as factors that align to corresponding indicators in the TIP directorate-wide approach to measure progress toward the directorate's three core goals. In this way, each program develops and maintains a distinct theory of change, while contributing to efforts to track impact across the TIP directorate's investment portfolio.

Logic Model - Program



Assumptions:


Intermediate outcomes
Long-term outcomes
Impact
TIP's core pillars
... and create the intended effect...
... to fulfill the long-term goals...
... and address the societal needs ...
Diverse Innovation Ecosystems
Logic model element
Logic model element
Logic model element
Technology Translation and Development
Workforce Development
Contextual factors