DELIVERING ON THE PROMISE OF CHIPS AND SCIENCE

Lab-to-Market Translation at NSF's TIP Directorate

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This paper series was designed to provide a brief overview of specific issues identified in the Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act of 2022. These papers are not meant to be exhaustive.

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Delivering on the Promise of CHIPS and Science Report Series

This report is part of a four-part series of research primers produced by the Technology and Public Purpose (TAPP) Project focused on the implementation of the 2022 CHIPS and Science Act.

Report Topics

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2. Community Colleges and the Semiconductor Workforce
3. Standard Setting: Process, Politics, and the CHIPS Program
4. Catalyzing Semiconductor Innovation through a National Semiconductor Technology Center

Each report topic formed the basis of a discussion organized by the Boston Tech Hub Faculty Working Group.

About the Boston Tech Hub Faculty Working Group

The Boston Tech Hub Faculty Working Group (FWG) was founded by former Secretary of Defense and Belfer Center Director Ash Carter and Harvard John A. Paulson School of Engineering and Applied Sciences Dean Frank Doyle. From February to May 2023, the group held monthly discussion-based meetings with senior faculty across Harvard and MIT and practitioners/decision makers across the public and private sectors that sought to explore and answer the questions: “How do we execute on the promise of the CHIPS and Science Act in an effective way?” and “Where do we go from here?”

The report authors would like to thank the Boston Tech Hub Faculty Working Group speakers and attendees for their contributions to each session.

Session Topics

- “Advancing Strategic Translational Science at the newly authorized TIP Directorate.”
  Guest Speakers: Erwin Gianchandani, Stacey Dixon, Edlyn Levine, Steven Currall
- “Leveraging America’s Potential - Workforce Development for the Semiconductor Industry.”
  Guest Speakers: Sujai Shivakumar, Bo Machayo, Anastasia Urtz, Jared Ashcroft, John Katko
- “Standard Setting and CHIPS Legislation Implementation.”
  Guest Speakers: Naomi Wilson, Mary Saunders, Andrew Updegrove
- “Catalyzing Semiconductor Innovation through a National Semiconductor Technology Center.”
  Guest Speakers: Susie Armstrong, Jim Cable, Dev Shenoy, Gregg Bartlett

Executive Summary

The 2022 CHIPS and Science Act is landmark legislation that aims to advance U.S. global leadership in science and technology. The CHIPS and Science Act––one part of the Biden-Harris administration's wider industrial strategy––was passed amid the rapidly accelerating geostrategic and technological competition between the U.S. and its main rival, China.

China, seeking to increase its global influence, has in recent decades invested heavily in technological research and development to advance its own economic goals and decrease its dependency on foreign countries. These investments have resulted in the successful scaling and capacity building of its domestic technology hardware sector and in emerging technology sectors such as Artificial Intelligence (AI) and quantum computing. If the U.S. is to maintain leadership in these, and other, strategic technology industries, it must bolster its domestic use-inspired research and development ecosystem.

One major effort through which CHIPS and Science seeks to achieve this is the creation of the Technology, Innovation, and Partnerships (TIP) Directorate at the National Science Foundation (NSF). The TIP Directorate's mission is to advance use-inspired research at NSF, particularly in areas of technology critical to strategic competition. TIP comprises both new and already existing initiatives, including the flagship Small Business Innovation Research (SBIR) program, which is called America's Seed Fund. Given that NSF historically has focused on basic research, TIP will face challenges both internally––as it is a major component of NSF's emphasis to focus more on use-inspired research––and externally to overcome the "valley of death," comprising challenges common to commercializing innovative technologies.

These obstacles are mainly clustered within three critical junctures throughout the innovation life cycle. The first obstacle occurs between ideation and prototype, as the gap between research and entrepreneurship skills must be met to identify profitability of technologies. The second obstacle occurs as a technology is scaled from prototype to business, where challenges associated with critical technologies–– such as technical risk, market risk, and regulatory risk––must be addressed. The third obstacle occurs as a technology reaches maturity. This happens when challenges to attract sufficient capital and navigate existing market tensions can impede the ability to scale and commercialize successfully.

Finally, TIP operates within a wider innovation ecosystem requiring a well-developed domestic industrial base to remain competitive with foreign research and development. It is critical to deeply understand this wider ecosystem and to take steps to grow and improve it if the U.S. is to remain a global leader in technological competitiveness. The below recommendations offer potential solutions to addressing each obstacle mentioned above and to navigating the strategic competition that underlies the entire process.

Summary of Recommendations

Obstacle 1: Ideation to Prototype

Recommendations for NSF TIP

- Focus on projects in key areas that program managers with close connections to the business community can assess as having a potential for profitability.
- Track publicly the key metrics of success for relevant technologies such as patents, publications, licenses, disclosures, company spinout, follow-on investment, strategic partnerships, public funding, time, and amount to first revenue and first profit.
- Include additional stipulations to awards given to academic institutions, as expanded upon in this primer, to generate a pipeline of academic ideas to the market.
- Expand I-Corps and Activate fellowship into longer term training and rotational opportunities to forge closer relationships with the private sector and academia.
- Expand fellowships/short-term exchange programs from NSF to the private sector.

Obstacle 2: Scaling from Prototype to Business

Recommendation for the National Institute of Standards and Technology (NIST)

- Develop standards for investors to use in determining the technological readiness level (TRL), specifically for emerging and critical technologies.

Recommendations for NSF TIP

- Set up a yearly symposium similar to ARPA-E's Energy Innovation Summit where awardees, potential investors, clients and regulators can interact.
- In future funding requests to Congress, TIP should differentiate between funding needed to start up versus scale-up new technologies.
- Use the special hiring authorities under Section 10396 of the CHIPS and Science Act to bring in outside talent on short-term (one to two years) contracts as advisers on unique investment opportunities for strategic technologies.
- Regularly review use-inspired projects for their deployability.
- Build a pre-commercial scaling program..

Obstacle 3: Growth to Maturity

Recommendation for venture capital (VC) firms

- Establish the position of chief science officer, who will be responsible for assessing technical risk.

Recommendations for NSF TIP

- Embed tech-to-market advisers in each of their projects, which increases exposure to the investment community.
- Expand pathways for career public servants in the innovation space at NSF to enter the private sector and re-enter public service.
- Establish a system in which program managers work alongside scientists and engineers to assess technical readiness for scaling.

Strategic Competition

Recommendation for the Office of Science and Technology Policy (OSTP)

- Direct the interagency working group mandated by Section 10651 of the CHIPS and Science Act to pay special attention to the quality of regional innovation ecosystem and talent development, thereby creating a regional innovation index.

Recommendation for Congress

- Establish and fund a directive to measure TIP's program outcomes.

Recommendation for NIST

- Develop a list of standard components necessary to properly measure emerging technologies and execute on that list for ten key technologies identified in CHIPS and Science Act.

Key Concepts

The following key concepts are found in legislation, public statements and proposals on this topic, and are used in this primer

- ***Strategic translational science* involves the process of moving research projects through developmental stages to produce usable technologies, innovations, or processes that are critical for maintaining a national technological advantage.** These technologies are strategic in nature because they enable other functions and support multiple applications across many sectors and will bolster the United States' technological edge to allow it to compete both militarily and economically. These technologies also promise to have significant impacts in shaping how the world functions in the coming decades. While the term "translational" is used in other disciplines––most frequently in biomedicine––those uses do not apply to this paper. The CHIPS and Science Act also makes frequent use of the term in describing the kind of research this paper discusses.

- ***Fundamental research* aims to expand fundamental knowledge and understanding without any immediate practical application or commercial objective. It is driven by intellectual curiosity, seeking to discover underlying truths and relationships.** Fundamental research serves as a foundation for applied research, innovation, and development by providing critical insights that can lead to breakthroughs. It focuses on advancing knowledge without any specific commercial outcome in mind.

- ***Applied research* is both purposeful and targeted. It is research conducted with a specific goal to solve practical problems rather than with the objective of furthering knowledge for its own sake.** This research focuses on the application of existing knowledge to develop innovative solutions and technologies that have practical relevance. Applied research bridges the gap between theory and development.

- ***Use-inspired research* refers to research that seeks a "fundamental understanding of scientific problems while at the same time having a clear and direct use for society."[1]** Use-inspired research can include but is not limited to the application of basic science. It also encompasses research that seeks to advance an existing scientific field and research that seeks to create entirely new scientific fields.[2] The CHIPS and Science Act explicitly states in Section 10381 that the TIP Directorate should "support use-inspired and translational research."

- ***The valley of death* is a common pitfall in an innovation cycle where concepts generated from basic, applied, or use-inspired research fail to result in a usable technology coming to market or otherwise failing to come into widespread use.** There can be several "valleys," or series of challenges, involved in the development process of a technology, and a critical "valley" exists between on the one hand, initial funding (often from the government) for research and proof of concept, and on the other, private funding resulting in prototypes and eventual scaling and production. Valleys are often categorized by company maturity milestones (e.g., obtaining a prototype, manufacturing at scale, etc.). Projects fall into the valley of death for several reasons including, but not limited to, that the research or technology is not yet ready to move forward scientifically, further funding is not available, market interest has changed, lack of commercialization, or because of regulatory or bureaucratic barriers.

Part 1: Geopolitical Context

What geopolitical factors led to the creation and passage of the CHIPS and Science Act?

- **China—the United States' most significant geopolitical competitor—has been investing heavily in R&D for emerging technologies[3] as part of a larger effort to become a global superpower and continue its transition from a developing economy to an advanced economy while avoiding the middle-income trap.** China seeks to continue its rapid economic growth partly through investments in research and developing advanced technologies that it can export to other countries or that its own citizens can afford to consume. This fits into China's larger objective of becoming a consumer-based economy with advanced manufacturing capabilities in several emerging tech sectors.[4] These investments are part of a concerted effort to establish a competitive advantage in research and advanced manufacturing for technologies key to the future economy and to establish a parallel global system to the U.S.-led "rules based international order."[5] Many of these technologies could also be categorized as "dual use," meaning that they have both military and civilian applications, heightening the risk of disparities in the sophistication of these technologies.
    - An important aspect of U.S.-China technological competition is China's exploitation of vulnerabilities to U.S. intellectual property (IP) protection. China does not adhere to international norms surrounding IP protection and strategically invests in foreign businesses to illegally adopt IP.[6] As China acquires foreign IP––both legally and illegally––it can then capitalize on its economies of scale to produce and sell goods at prices competitive to the global market.

- **One part of this overall strategy is Made in China 2025, which began in 2015 as a decade-long campaign to invest in developing ten high-tech industries that China sees as key to being successful in the "Fourth Industrial Revolution," which is characterized by cyber-physical interconnected systems.**[7] By 2025, China wants to achieve 70 percent self-reliance in its own high-tech industries and by 2049 wants to attain a dominant global position in these industries.[8]
    - The ten technologies are: electric cars/other new energy vehicles; information technology (IT) and telecommunications; advanced robotics and AI; agricultural technology; aerospace engineering; new synthetic materials; advanced electrical equipment; biomedicine; high-end rail infrastructure; and high-tech maritime engineering.[9]
- **China wants to reduce its dependence on high-tech products from foreign countries.**[10] While China excels at mass producing readily available technologies like smartphones and other electronics, it has lagged behind other countries in developing cutting edge tech, such as the most advanced semiconductors.[11] China wants to build the capacity to innovate and produce the highest end technologies domestically.
    - **China also wants to reduce its economic reliance on low-value added businesses and low-wage manufacturing jobs.**[12] To do so, China is investing in high-tech and upstream economic inputs, rather than downstream, low-end manufacturing capabilities.
- **China is especially successful at scaling and capacity building in the technology hardware sector. Huawei, for example, experienced rapid growth––partially due to extensive state support––prior to becoming the target of U.S. sanctions.**[13] China's technology hardware sector has been largely directed by the Chinese Communist Party (CCP) and reflects its traditional industrial policy of selecting successful ventures and giving them a boost though illicit subsidies, predatory trade practices, and espionage––such as the Semiconductor Manufacturing International Corporation (SMIC)[14] and Yangtze Memories Technology Corporation (YMTC), which are both partially state-owned enterprises.[15] China previously had a more active and innovative software sector, which was fairly independent of the government, but the CCP has curtailed some of its activities and limited its autonomy in recent years.[16] There are signs, however, that this trend may be beginning to reverse.[17]
- **In recent years, many analysts assert that China's emerging tech sectors rival or surpass some of its Western competitors, especially in areas like AI[18] and quantum computing.**[19] The CCP has several talent related efforts to increase its relative competitiveness in these and similar areas.[20] Although the CCPs oversight of its industries can hamper innovation, it can also facilitate the massing of resources to prioritized sectors, like semiconductors and telecommunications equipment.[21] Much of this top-down resource prioritization, while wasteful and inefficient, has buttressed several domestic industries in China due to the enormity of the investments.[22]

- **China has also invested heavily in talent and taken advantage of many highly educated citizens who have studied at U.S. universities and completed PhD programs. Most then return to China and many work in emerging tech sectors––contributing to the country's ability to rapidly scale its companies.**[23] The Thousand Talents Program also recruits science and technology experts from abroad to come to China and contribute to these efforts.[24] Furthermore, the CCP has often engaged in sophisticated espionage and intellectual property theft, allowing it to identify unique emerging technologies from abroad, import those ideas, and then quickly produce them at scale.[25]

- **The CHIPS and Science Act represents an initial response to China's R&D push and investments in emerging technologies. Beyond China, CHIPS and Science also seeks to reinvigorate U.S. tech R&D and enable the U.S. to compete globally in key technologies.** Other legislation––such as the Infrastructure Investment and Jobs Act and the Inflation Reduction Act––have also provided major resources that will contribute to increasing U.S. technological competitiveness. Concerns that the U.S. has already fallen behind in some advanced technologies such as semiconductors, and could continue to do so, leading to technological surprise were a major driver of the CHIPS and Science Act. Historical examples––ranging from nuclear technology to the internet––provide meaningful touchpoints for why gaining an edge in emerging technology can provide global economic and military advantages for a country. A stronger use-inspired research sector can help lead the way for an innovation-based economy.

- **Division A of the CHIPS and Science Act focuses on semiconductor competitiveness. Division B of the Act focuses on scientific research and innovation.** Within Division B, the CHIPS and Science Act authorizes the TIP Directorate within NSF.

- **TIP's mission**, according to its website, is to harness "the nation's vast and diverse talent pool to advance critical and emerging technologies, address pressing societal and economic challenges, and accelerate the translation of research results from lab to market and society. TIP improves U.S. competitiveness, growing the U.S. economy and training a diverse workforce for future, high-wage jobs."[26]

- **The text of the CHIPS and Science Act directs 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."[27]

Question for further research

How does China's approach to investing in lab-to-market translation of critical emerging technologies compare to U.S. strategies?

Part 2: A Deeper Dive on the TIP Directorate

Why was the TIP Directorate created at NSF?

- **NSF mainly funds fundamental science and engineering research.** From the first observation of a black hole to the measurement of gravitational waves and climate research, NSF supports curiosity-driven research across a range of disciplines mainly at colleges and universities. At a recent appropriations hearing, NSF Director Sethuraman Panchanathan said that the "commitment to funding fundamental exploratory based research...is the heart of NSF's mission".[28]

- **NSF increasingly looks for new avenues of research that transcend historical boundaries.[29]** For instance, use-inspired research occurs at the intersection of fundamental research and end-use considerations. Pasteur's Quadrant[30] is a model science that identifies three types of research: curiosity-driven basic, use-inspired basic, and applied. As framed in the CHIPS and Science Act, TIP will address the need for more use-inspired basic research while advancing regional development initiatives with a greater focus on both critical technology competitiveness and addressing societal needs.[31]

- **NSF introduced the successful SBIR program called America's Seed Fund.** In 1977, NSF began dedicating a fraction of its budget for grants to small businesses operating within its areas of expertise. The program was effective and eventually replicated at multiple federal agencies. Since 1982 every major federal research agency is required to set aside a percentage of its budget––now 3.2 percent––for SBIR. Today, SBIR consists of a three-phase startup development program with grants ranging from $100,000 to $1 million in the first two phases. The SBIR program at NSF has been impactful: companies like iRobot (maker of the Roomba), Sonicare, Qualcomm, and Symantec (computer security, Norton antivirus) have all received seed funding from NSF's SBIR program.

- **While the SBIR program is the flagship initiative aimed at accelerating translational science, it has experienced several challenges.** The program has been criticized for not offering sufficient support toward companies designing a business model or generating early market studies with customer discovery.[32] The program also lacks longer-term funding in the third phase, where companies that fail to grasp a market share often struggle with commercialization for years. It has also been targeted for inefficiencies, funding so-called "SBIR mills,"[33] and exposing government-funded American startup's IP to Chinese theft.[34] This criticism is addressed in the SBIR renewal bill.[35] Compared to other federal research funding agencies, NSF's SBIR portfolio skews toward younger first-time awardees (over 80 percent of all grants).[36]

What is the TIP Directorate and which parts of the TIP Directorate are focused on translational science?

- **Authorizations:** Subtitle G of Title III of the CHIPS and Science Act Division B established the NSF TIP Directorate, authorizing $20 billion in funding for the Directorate over fiscal years 2023–2027 and $81 billion for NSF overall.[37] It is important to note that authorization legislates the total amount of funding that could be made available to NSF for the TIP Directorate, not the amount NSF is provided to spend. The appropriations package legislates the amount of funding to which NSF has access for that appropriations cycle.[38]
    - **Appropriations:** NSF's total appropriations package for Fiscal Year 2023[39] is $9.87 billion,[40] including $335 million dedicated to fulfilling the goals of the CHIPS and Science Act. It is estimated that the TIP Directorate will receive $880 million. For FY 2024, NSF has requested a budget of $11.3 billion, a 28 percent increase over enacted 2023 levels. This includes $1.2 billion planned for the TIP Directorate[41]
- **TIP is a combination of new and existing programs at NSF focused on advancing the lab-to-market translation of critical technologies. One of TIP's objectives is to help the United States strengthen its technological advantage in order to remain competitive in the 21st century.** The legislation seeks to help bridge the valley of death and kickstart the innovation of critical technologies. NSF TIP is not the only solution to spurring U.S. innovation and bridging the valley of death, but it is an important initiative legislated by CHIPS and Science to help do so.
- **NSF TIP has a statutory mandate to focus on ten technologies seen as key to maintaining a future edge to overcome specific social, national and geostrategic challenges. The CHIPS and Science Act enumerates these challenges: national security, manufacturing and industrial productivity, workforce development and skills gaps, climate change and environmental sustainability, and inequitable access to education, opportunity, or other services. The technologies NSF TIP will focus on are, therefore, strategic in nature from both a defense and economic growth perspective.**
    - The initial ten key technology areas (which NSF is to review annually) include software, like AI, data storage, and cybersecurity; hardware, like high performance computing, semiconductors, and robotics; and emergent topics, like quantum information science and technology, advanced energy efficiency, and advanced materials science. It also includes a focus on disaster prevention and biotechnology.
- **NSF already had, in its existing directorates, several efforts to translate technologies from the research phase to developmental prototypes and related projects.** TIP brought many of these existing programs under one roof and created new programs. Below is a list of TIP's current programs and initiatives.

- **Accelerating Research Translation (ART):** Supports institutions of higher education to build capacity and key infrastructure for the translation of fundamental research into tangible solutions for the public good.
- **NSF's SBIR Program, also called America's Seed Fund:** Awards of $200 million in seed funding to over 400 projects annually for technologies that demonstrate promise but have not yet been validated.
- **Convergence Accelerator:** Funds the fusion of teams to solve societal challenges through the convergence of research and innovation.
- **Enabling Partnerships to Increase Innovation Capacity (EPIIC):** Awards institutions up to $400,000 to support the growth of inclusive innovation ecosystems through capacity-building efforts at institutions of higher education with limited research capacity to prepare them to participate in NSF Regional Innovation Engines in the future.
- **Experiential Learning for Emerging and Novel Technologies (ExLENT):** Supports inclusive experiential learning opportunities that provide cohorts of diverse learners with the skills needed to succeed in emerging technology fields.
- **Innovation Corps (I-Corps):** a seven-week program for engineers and scientists that serves as an immersive entrepreneurship experience to develop their business acumen and further enable their basic research projects to be translated into products with widespread implementation.
- **Partnerships for Innovation:** Assists researchers and innovators from academia, nonprofits, and public organizations to accelerate the development of their technologies into university spinoff companies.
- **Pathways to enable open-source ecosystems (POSE):** Seeks to harness the power of open-source ecosystems to create new technologies and solve public purpose solutions.
- **Proto-Open Knowledge Network:** Supports the creation of a prototype "Open Knowledge Network." This is an interconnected network of knowledge graphs that supports a broad range of applications, including AI and others.
- **Regional innovation engines:** Funds regional technology development engines.[42] This program awards up to $160 million to each of 44 regional engines to support innovation ecosystems that advance critical technologies, address societal national challenges, cultivate multi-sector partnerships, and stimulate economic growth and job creation.
- **Activate Fellowship:** Activate Fellows supported by NSF will receive training and at least $350,000 in direct support, plus access to specialized research facilities and equipment.

Question for further research

With the establishment of TIP as a Directorate, how will existing programs continue or change, and what new programs are being introduced?

- How does the reorganization of existing programs and the additional initiatives achieve the goals of CHIPS and Science?
  - How could these programs make the United States more successful at strategic translational science?
  - What is the theory of change by reorganizing these programs under TIP and creating new programs?
  - How does TIP fit into the broader ecosystem of basic and applied research within the U.S. government?

What key internal challenges will NSF and TIP need to address?

- **While NSF works on the full spectrum of foundational to use-inspired basic research, TIP's mission focuses on the use-inspired side.** This can generate some friction as the purpose and scope[43] of NSF has been subject to debate over the years. From a historical lens, Vannevar Bush's perspective supported focusing on basic research.[44] with the ambition that funding fundamental science would have profound consequences for national strength and social good. Others,[45] for instance, have argued over time that a broad federal extramural science funding agency should more directly focus on applied science. Given that NSF has historically been predominantly recognized for its efforts on fundamental science, there are concerns today that it could move away from its area of expertise by implementing the TIP Directorate. However, this is incomplete, as NSF has maintained expertise beyond basic research over time (e.g., through the SBIR and Small Business Technology Transfer (STTR) programs, and with engineering research centers) while remaining effective in carrying out fundamental research.
  - Furthermore, it can be helpful to think of fundamental science funding as an ecosystem not limited to project-specific grants: Diversity, Equity, and Inclusion (DEI) initiatives, workforce training, regional implementation, talent support and public-private partnerships all contribute to a positive climate of innovation in fundamental science. Therefore, TIP should be viewed as the next step in this ecosystem support[46] and the way it defines its position will be critical in its effectiveness.
- **A large influx of funding at NSF will pose challenges for the foundation, as it grapples with how to effectively utilize resources at a much larger scale.**[47] This has been a concern in other agencies that received large funding increases from CHIPS and Science. For example, the

Department of Energy (DOE) Office of Science has scrambled to widen its workforce and is actively asking for input on how to effectively focus on the key technology areas.[48]

- **Another internal challenge the TIP Directorate will face is how to resolve overlap between its programs and those in the Department of Commerce and DOE**––for example regional innovation hubs. The stated intention[49] is for those to work closely together, and through Section 10651 of the CHIPS and Science Act, OSTP is empowered to coordinate these efforts. Yet, some programs may still overlap or generate confusion for applicants. So, special considerations must be taken to harmonize the funding processes for programs with similar goals across federal agencies.
- **As it charts its course for the next few years, the TIP Directorate will need to navigate competing priorities within NSF.** It is recognized by many that TIP currently does not divert funding or resources away from NSF's core stated goals. Rather, TIP augments the NSF's mission and supplements existing programs by offering use-inspired funding opportunities across all fields. This can create tension with other directorates as they may aim to persuade TIP to spend more on their area of focus, and in so doing, sidetrack TIP from its long-term national and societal goals. Indeed, TIP must be careful to avoid explicit short-term projects or long-term fundamental research that may fulfill other directorates' missions within the key technology areas. Instead, TIP needs to remain focused on its medium-term mission which is the hallmark of use-inspired science.
- **Funding innovative science can present major challenges. For instance, it is unclear how the five societal goals laid out for TIP in the CHIPS and Science Act will be weighed against the ten key technology areas.** In other words, given funding constraints, how are the wide-ranging goals of the TIP Directorate prioritized? It is clear that all of the technology areas have profound societal implications, but how to assess those and keep them aligned with the social goals remains elusive. Ethical statements and framing proposals in the context of broader implications are commonplace for NSF proposals, so that may be a good starting point when evaluating prospective projects. With good ethical guidelines and close ties with the community, fulfilling the societal goals may naturally flow from the key technology areas, or it may introduce conflict and opposition that would need to be resolved.
- **If NSF carefully addresses these internal challenges, the TIP Directorate has the potential to make a sizable impact in the key sectors identified by the CHIPS and Science Act.** For example, a meeting of academics and startup founders in the quantum information landscape recently issued recommendations for translational science topics, including a list of quantum demonstration projects that are mature for federally supported public-private partnerships.[50] These include developing the full-stack operation of quantum computers to address scientific and engineering grand challenges, and using those to run quantum simulations of high-impact scientific problems including fundamental physics, materials design, and quantum chemistry. The TIP Directorate could be leveraged to support similar projects, and in doing so, advance many of the ten key technology areas identified in its CHIPS and Science authorization.

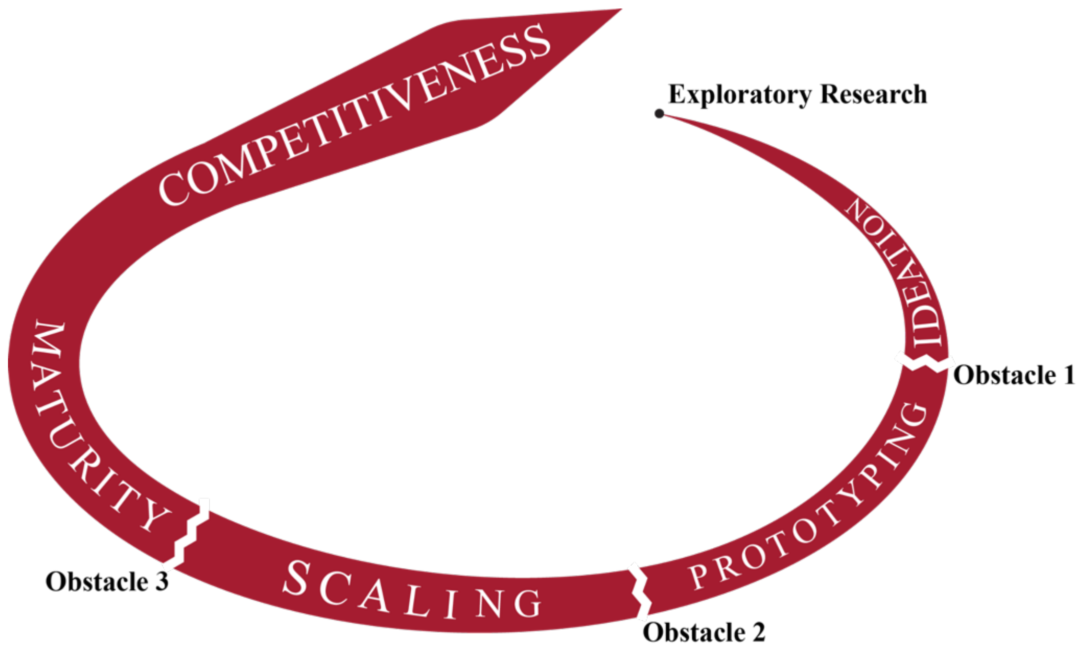
Part 3: Recommendations for TIP and Other Key Stakeholders

As a result of the internal tensions outlined in the previous section, some have questioned whether the TIP Directorate should reside within NSF, or whether NSF should borrow more directly from other government technology development initiatives. While there are other government efforts to facilitate the production of technologies from basic research to fully developed products–– Defense Advanced Research Projects Agency (DARPA) or In-Q-Tel for example––they very much differ from TIP's approaches, which creates limitations to applicability of lessons that can be extracted and applied to the TIP Directorate. Technologies developed by these other efforts are often the result of a specific government request. An organization like DARPA does not need to develop profitable companies, but rather an immediate proof of usability to its customer: the federal government. The TIP Directorate's mission is fundamentally different, as it is oriented not around the development of specific technologies but around the U.S. technological and economic competitiveness. To achieve its mission, technologies in which TIP invests must go beyond proof of usability; they must successfully commercialize.

As NSF seeks to advance translational science, it must overcome several obstacles common to the commercialization of deep technologies. These obstacles are mainly clustered within three junctures of the development cycle, as outlined in the above graphic. To ensure companies under the auspices of the TIP Directorate achieve market success, TIP must develop mechanisms to help companies overcome these "bumps in the road."

The following sections will further elaborate on the three "obstacles" for commercializing strategic technologies and provide recommendations that TIP and other relevant stakeholders can implement to mitigate the associated challenges. The final section further discusses strategic competition and additional steps the federal government can take to improve national competitiveness.

Figure 1. Cycle of Innovation and Critical Obstacles



Obstacle One: Ideation to Prototype

The first obstacle in translational science comes early on in the company creation process, where an idea grown out of experiments in laboratories, for instance, must be turned into a proof of concept that can be patented. This phase involves entrepreneurship skills including market studies, identifying potential consumer base, raising funds and early recruiting that can be distant from the abilities NSF-funded scientists rely on daily. Therefore, strong connections to the business community, management support to bring an idea to maturity, and reliable risk-tolerant funding are all critical to overcome this hurdle.

We recommend several steps to overcome these obstacles:

- **Recommendation for NSF TIP:** Focus on projects in key areas that program managers with close connections to the business community can assess as having a potential for profitability. By closely mapping project managers' expertise to key areas of competitiveness and leveraging a network of experts to assess the private-sector interest in an idea, TIP can help founders overcome the ideation hurdle. For a quantitative analysis of the various active project management tools, see this paper.[51]
- **Recommendation for NSF TIP:** More insightful metrics that reflect the regional hallmarks of innovation may be helpful in constructing a long-term model for the impact of TIP. These include

an entrepreneurship quality index[52] and a set of ecosystem metrics[53] that comprise resources and institutions, such as the percentage of a population with a business or tech education, the number of collaborations between new ventures, the number of startup incubators or coworking spaces per capita.

- **Recommendation for NSF TIP:** Publicly track the following key metrics of success identified[54] in the space: patents and publications, licenses, disclosures, company spinout, follow-on investment (from private investors, including acquisition or IPO), strategic partnerships, public funding, and time and amount to first revenue and first profit. These high-level metrics, in particular, when aggregated at the scale of a program, are very difficult to process. In part, gathering this data is challenging: surveys must be periodically filled out by awardees over long periods of time even after the end of the award. Also, no metric is without drawbacks. For example, increased patenting upon award may suggest a bias toward picking projects with patentability, acquisitions could suggest the failure of a venture (and buyout of its IP), the number of unicorns in a program is small and difficult to learn from statistically.

- **Recommendation for NSF TIP:** For awards given to academic institutions, include the following stipulations: (1) late career graduate students or postdoctoral fellow take a lead on the project, (2) these project leaders are expected to spend a small (5–10 percent) portion of the award money on writing a market analysis, meeting with stakeholders, take a business course or other similar activity, (3) provide coaching to those project leaders on how to make presentations to investors, (4) wherever possible, require that a business school faculty member of the same institution as the awardee co-sponsors the project and periodically checks in on the technical feasibility of a business venture. These are specific targets that can help generate a pipeline of academic ideas into the market.

- **Recommendation for NSF TIP:** Expand I-Corps and Activate fellowships into longer term training and rotational opportunities to forge closer relationships with the private sector and academia. Streamline the application process––current wait times can be up to a year. Efficient project managers collect ideas from academics and connect them with industry experts to facilitate the commercialization of academic work, while respecting the process and trust of academics. I-Corps and Activate can help TIP-funded founders forge those connections themselves, with the assistance of the Directorate.

- **Recommendation for NSF TIP:** Expand fellowships and short-term exchange programs from NSF to the private sector. Bi-directional flow of experts within the innovation space is important, as it allows those from diverse backgrounds to develop a deeper understanding of the ecosystem as a whole. Improving accessibility to and encouraging participation in tours of duty in the private sector foster connections between public/private leaders in innovation, as well as professionally enrich public servants.

Obstacle Two: Scaling from Prototype to Business

The second obstacle most common to the program development cycle is the ability to successfully scale an existing company with a promising prototype. There are several risk factors that contribute to the scalability challenge: technical and engineering risk, market risk, business model risk, political and regulatory risk, and scientific feasibility risk. Potential investors at this point are trying to determine whether the technology will provide a meaningful return on investment that can result in a profit. They also need to determine whether the prototype, although functioning in a lab setting or on a limited scale, is actually useful in the real world. Even if the technology is determined to have profit potential and be technically feasible, there are remaining concerns that adequate resources––such as access to materials, talent, and manufacturing facilities––in addition to capital, may not be available.

We recommend several actions to overcome the challenges present at this juncture:

- **Recommendation for NIST:** Develop standards for investors to use in determining technological readiness levels (TRL) for emerging and critical technologies at the sector-wide/national level, rather than for TIP's use only. VC firms are well acquainted with commercial risk but may lack the expertise to run reliable assessments of technical risk which are inherent to non-traditional technology companies. By creating a national, accessible set of TRLs for certain emerging technology sectors, NIST can help funders understand where a technology stands in the development cycle. NIST will need to leverage expertise from across academia, the government, and the larger scientific community to develop TRLs for various sectors––from quantum computing to AI or fusion energy research.
- **Recommendation for NSF TIP:** In future funding requests to Congress, TIP should differentiate between funding needed to start up versus scale-up new technologies. Differentiating categories of funding will help TIP explain to Congress why it requires the levels of funding requested.
- **Recommendation for NSF TIP:** In addition to the expansion of existing programs, use the special hiring authorities under Section 10396 of the CHIPS and Science Act to bring in outside talent on short-term (one to two years) contracts as advisers on unique investment opportunities for strategic technologies. Such a program will not only develop investors who are scientifically minded, but also could create opportunities for scientists to become investors in emerging technology.
- **Recommendation for NSF TIP:** Regularly review use-inspired projects for their deployability (i.e., whether they can be manufactured at scale, be reliable under commercial utilization, integrated with existing systems, leverage existing production, materials and workforce structures, etc.). This can be done at the discretion of the project manager with input from

the tech-to-market adviser. It is important to accept additional risk. Studies have found that an overwhelming majority of the value of private sector and university innovation efforts is concentrated in 10 percent of the technically successful ventures.[55]

- **Recommendation for NSF TIP:** Build a pre-commercial scaling program similar to ARPA-E's SCALE-UP. At ARPA-E, this program targets successful early ventures that struggle to build prototypes at scale to demonstrate the viability, reliability and integration of their technology. By infusing sufficient capital for large-scale pilot programs (including manufacturing facilities and processes), they can validate the technology and business model of risky ventures enough to attract equity from the private sector. In its first year, the program had received $1 billion worth of applications[56] and provided $70 million in funding.[57] Features of the TIP scale-up program should include:
    - Award amounts three to five times greater than the average early venture TIP award (at ARPA-E, SCALE-UP award[58] ranges $5–20 million, whereas the average[59] 3-year ARPA-E award is $2.5 million).
    - Require a portion of the funding to come from private financial partners through a cost-sharing mechanism, thus jumpstarting the handoff to private investors. TIP can facilitate this through pitch competitions and investor-award finalists symposia.
    - Require industry or consumer partners to join the project, for example as advisers or hosts of pilot projects, thereby building closer ties with the market and manufacturing capabilities.

Obstacle Three: Growth to Maturity

While obstacle two addresses the challenges associated with ensuring a technology is able to initially scale, obstacle three includes the barriers associated with a technology's growth to maturity. Unlike other government commercialization efforts such as DARPA and In-Q-Tel, the technologies in which TIP invests do not generally have a government buyer. Thus, TIP start up/scale ups must attract private capital to successfully scale and commercialize businesses. However, characteristics inherent to emerging technologies do not always create the proper market incentives to attract private capital. Emerging technologies often do not follow traditional development timelines, nor do they meet typical return expectations within three to five years of investment. That is why early-stage funding is often public.

To overcome challenges associated attracting private capital amid difficult to measure return periods, several actions are recommended:

- **Recommendation for NSF TIP:** Embed tech-to-market advisers (similar to ARPA-E) in each project, which increases exposure to the investment community. Tech-to-market advisers should be experienced startup founders, innovators or venture capitalists with a precise knowledge of a key technology focus area. They will foster connections between TIP awardees and clients, investors, and regulators. In addition, they can help the founders develop business models and perform market studies, thereby building their entrepreneurship skills.

- **Recommendation for VC firms:** Establish the position of chief science officer, who will be responsible for assessing technical risk. This will enable VC firms (and large companies) to understand technological readiness of non-traditional technologies and broaden risk tolerance, ultimately encouraging more capital flow to technology start ups.
- **Recommendation for NSF TIP:** Expand pathways for career public servants in the innovation space at NSF to enter the private sector and re-enter public service. By improving accessibility to gain private-sector experience, career public servants at TIP can approach the execution of its programs with first-hand, holistic understanding of the innovation ecosystem.
- **Recommendation for NSF TIP:** Set up a yearly symposium similar to ARPA-E's Energy Innovation Summit where awardees, potential investors, clients and regulators can interact. This venue has proven successful in generating follow-up funding for ARPA-E's ventures.
- **Recommendation for NSF TIP:** Establish a system in which program managers work alongside scientists and engineers to assess technical readiness for scaling. Ensure portfolios are selected with approval from engineers that the technology is ready for scaling and is not still in a development phase.

Strategic Competition

Strategic competition in military, economic, and technological domains remain a key driver behind the CHIPS and Science Act and an important touchpoint for TIP. To compete successfully on technologies that drive military and economic prowess, the United States needs to be able to innovate quickly––which it does––and scale those innovations effectively and efficiently––which it often struggles to do. The innovation ecosystem in the United States is enormously successful. However, the ability to expand small startups with great ideas and to mass produce high-end technology remains a challenge, due to an inadequate industrial base. This creates a challenge for commercialization, as technologies are not able to achieve economies of scale necessary to lower production costs.

To meaningfully contend in an era of increasing strategic competition, the United States needs to develop a greater industrial commons that innovators can leverage to scale their products.[60] Understanding how well the United States is accomplishing its goals competitively requires measuring its own progress. While the responsibility of measuring U.S. competitiveness relative to other countries is not TIP's alone, it is nevertheless imperative to measure and understand the state of U.S. competitiveness to ensure that resources are used efficiently and effectively toward achieving broad strategic goals.

To accomplish this task, the United States should develop tailored measurement tools to assess the state of national competitiveness for these technologies compared to other countries. While measuring patents and licenses is meaningful for understanding the pace of innovation for individual companies, these metrics alone do not necessarily reflect national competitiveness overall. The ability to act upon and scale such innovative efforts is the second critical component of competing effectively. China has undertaken extensive efforts to improve its innovation ecosystem and it is necessary that the United States not only improve its ability to scale strategic technologies, but to also measure the impact of its efforts.

Strategic competition is a challenge that takes place outside of the "three-obstacle" framework of the development cycle but nevertheless requires certain recommendations to overcome:

- **Recommendation for OSTP:** Direct the interagency working group mandated by Section 10651 of the CHIPS and Science Act to pay special attention to the quality of regional innovation ecosystem and talent development, thereby creating a regional innovation index. Also, expand beyond an assessment of exclusively federal programs, and monitor collaborative research bridging federally funded academia and industry partners (e.g., university-based quantum research centers of Amazon, Google, and others) and also research beyond the national borders, with government and industry partners abroad (e.g., partnerships with ASML, TSMC, ITER). This interagency working group, led by OSTP, is required under the CHIPS and Science Act to report to Congress the current state of federal programs and coordinate activities on key strategic technology areas across agencies.
  - **Follow-up Recommendation for NIST:** A robust agency with experience developing metrics should take the lead to assess innovation at the regional scale. The Department of Commerce (a member of the working group) through NIST should analyze the measurements used for innovation outlined in Obstacle one, but also expand beyond those. NIST could measure the U.S. market share of strategic technologies compared with that of other national competitors as a metric of success. In particular, to understand long-term effects, NIST can collect and curate data on which countries maintain leadership in a technology over multiple generations of product development. For example, data could be collected along benchmarks such as (1) first to market; (2) persistence in market (e.g., offshored production and offshore second generation innovation); (3) leadership over multiple generations of product development/innovation.[61]

- **Recommendation for Congress:** Establish and fund a directive to measure TIP's program outcomes. Funding and tools to measure success within TIP's programs will enable the U.S. government to evaluate TIP's overall effectiveness in commercialization efforts. These measurement and assessment tools are needed to view investments and scaling on a multi-year or even decade timeframe. Many strategic technologies––the internet for example––take decades to have significant positive economic outcomes resulting from early-stage investments. Oftentimes, failure can be quickly identified, but a technical innovation success may take years to be recognized as such.[62] Measurements of success should take this into consideration.
- **Recommendation for NIST:** Develop a list of standard components necessary to properly measure emerging technologies and include those for the ten key technologies identified in CHIPS and Science Act. These components include developing a lexicon of standard vocabulary to begin measuring development in emerging technologies, as exemplified in President Biden's recent Executive Order for the biotechnology field.[63] The ability to measure the state of U.S. competitiveness against China is dependent on the U.S. ability to measure progress within individual technologies' development.

About the Technology and Public Purpose (TAPP) Project

The arc of innovative progress has reached an inflection point. It is our responsibility to ensure it bends toward public good.

Technological change has brought immeasurable benefits to billions through improved health, productivity, and convenience. Yet as recent events have shown, unless we actively manage their risks to society, new technologies may also bring unforeseen destructive consequences.

Making technological change positive for all is the critical challenge of our time. We ourselves - not only the logic of discovery and market forces - must manage it. To create a future where technology serves humanity as a whole and where public purpose drives innovation, we need a new approach.

Found by former U.S. Secretary of Defense Ash Carter, the TAPP Project works to ensure that emerging technologies are developed and managed in ways that serve the overall public good.

TAPP Project Principles:

1. Technology's advance is inevitable, and it often brings with it much progress for some. Yet, progress for all is not guaranteed. We have an obligation to foresee the dilemmas presented by emerging technology and to generate solutions to them.

2. There is no silver bullet; effective solutions to technology-induced public dilemmas require a mix of government regulation and tech-sector self-governance. The right mix can only result from strong and trusted linkages between the tech sector and government.

3. Ensuring a future where public purpose drives innovation requires the next generation of tech leaders to act; we must train and inspire them to implement sustainable solutions and carry the torch.

For more information, visit: www.belfercenter.org/TAPP

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